ASD-TDR-63-7-695A PT-675

FINAL REPORT ON

ENGINEERING AND PRODUCTIZATION OF AN INTEGRATED FAMILY OF BACKWARD WAVE OSCILLATORS

VOLUME - ONE

Technical Documentary Report No. ASD-TDR-63-7-695A

October 1963

Electronics Branch Manufacturing Technology Division
Air Force Materials Laboratory
Research and Technology Division
Air Force Systems Command
U.S. Air Force
Wright-Patterson Air Force Base, Ohio

ASD PROJECT 7-695A

Prepared Under

Contract: AF33(600)-43395

Prepared by

RAYTHEON COMPANY
Microwave and Power Tube Division
Spencer Laboratory
Burlington, Massachusetts

Peter Janis
James Gallagher

VOLUME 1 of 2

NOTICES

FOREWORD

This Final Technical Engineering Report covers the work performed under Contract Number AF33(600)-43395 from 7 July 1961 to 7 January 1963. The manuscript was released by the authors on 22 February 1963 for publication as an ASD Technical Report.

This contract with the Microwave and Power Tube Division of Raytheon Company, Burlington, Massachusetts, was initiated under ASD project 7-695, "Contract for M-Type BWO Program," It was administered under the direction of Mr. Arnold March, Senior Project Engineer, ASRCTE, Electronics Branch, Aeronautical Systems Division, Air Force Systems Command, Wright-Patterson Air Force Base, Ohio.

The objectives of the program were to redesign, refine, production-fabricate and evaluate a compatible series of M-type backward-wave oscillators, as follows: QKA851 (1300-1850 Mc; 200 watts power output), QKA852 (1800-2550 Mc; 200 watts power output), QKA855 (4800-6550 Mc; 150 watts power output) and QKA857 (8500-11,000 Mc; 150 watts power output).

The project was conducted under the general supervision of Dr. Howard Scharfman, Manager of Engineering, Microwave and Power Tube Division, and Mr. Edward C. Dench, Manager, Crossed-Field Devices Laboratory. Mr. Peter Janis, Engineering Section Head, was project engineer on the QKA851 and QKA852 for the entire period of the program and had general supervision of the QKA855 and QKA857 program during Phase II. Mr. Janis was assisted by Mr. Richard McCarthy, Mr. Kenneth Morman, Mr. James Gallagher, Mr. Richard Deming and Mr. John George. Mr. Russell T. Mannette, Engineering Section Head, was project engineer on the QKA855 and QKA857 programs during the Phase I effort; he was assisted by Mr. John George, Mr. Richard Deming and Mr. Thomas Lavin.

ABSTRACT
Final Technical Documentary Report

ASD-TDR-7-695A
October 1963

FINAL REPORT ON ENGINEERING AND PRODUCTIZATION OF AN INTEGRATED FAMILY OF BACKWARD-WAVE OSCILLATORS

Peter Janis
James Gallagher

Raytheon Company

A family of electrically and mechanically compatible electronically tunable M-type backward-wave oscillators has been developed. The tubes of this series have been redesigned and production refined, and small quantities of each tube type have been fabricated and subjected to stringent electrical and environmental tests. Optimum tube designs have been achieved to meet the requirements of the new ASD coordinated exhibit. Cost reduction has been obtained through the use of many common parts and through the establishment of economical manufacturing methods. The tubes have been designed for processing on the mass-production in-line exhaust system.

The previously developed tubes were analyzed and evaluated, and designs were modified as necessary to meet the requirements of the new specifications and contract objectives. Electrical, mechanical and process specifications were derived. To prove the validity of the specifications and the quality of the tube designs, samples of each tube type were fabricated and evaluated. Further modifications and retesting were accomplished wherever necessary.

As a result of this program, Raytheon has developed production capability covering seven of the nine frequency bands outlined in the ASD coordinated exhibit. Meanwhile, Raytheon's extensive experience in the development and transfer to mass production of backward-wave oscillators will permit rapid extension of this capability to the remaining two bands if the necessity arises.

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PUBLICATION REVIEW

This report has been reviewed and is approved.

FOR THE COMMANDER:

Melvin E. Fields

MELVIN E. FIELDS, Colonel, USAF
Chief, Manufacturing Technology Division
Air Force Materials Laboratory

Engineering and Productization of an Integrated Family of Backward Wave Oscillators

TABLE OF CONTENTS

Table of Contents (Continued)

LIST OF ILLUSTRATIONS

List of Illustrations (Continued)

List of Illustrations (Continued)

Engineering and Productization of an Integral Family of Backward-Wave Oscillators

INTRODUCTION

The purpose of this contract was to reorient current manufacturing methods in such a manner as to provide the Air Force with one family of compatible broadband integrated coverage "M" type Backward Wave Oscillators.

Phase I of this program was directed toward redesigning and productizing four tube types to a point where large quantities can be built at high yields.

Phase II of this program was directed toward production fabricating a minimum of six tubes of each type utilizing the finalized design and construction practices and subjecting these tubes to all environmental and life tests required by the finalized specification data.

The tubes comprising the entire family are listed below:

Band	Tube Type	Frequency-MCPS	Min Power Output-Watts	RF Output
1	QKA850	1000 - 1400	200	7/8 Coaxial
2	851	1300 - 1850	200	7/8 Coaxial
3	852	1800 - 2550	200	7/8 Coaxial
4	853	2500 - 3550	180	7/8 Coaxial
5	854	3500 - 4850	180	7/8 Coaxial
6	855	4800 - 6550	165	DR-19
7	856	6500 - 8550	150	DR-19
8	857	8500 - 11000	150	DR-19

Although work was begun simultaneously on the four tubes involved in this program, namely the QKA851, 852, 855 and 857. The engineering effort was scheduled in accordance with the priorities specified in the contract: Priority I, QKA857 and QKA855; Priority II, QKA851 and QKA852.

Raytheon will not develop bands 5 and 7 at the present time. The compatible band 4 tube was in production at Raytheon at the time this contract was initiated.

The compatibility concept was spearheaded by the Air Force as a result of their foresightedness and funding under contracts AF33(600)-37156 and AF33 (600)-35096. These contracts yielded the QKA657, QKA658, QKA660 and the QKA634/773 from which the designs for the current compatible family are based.

Due to the continuous acceptance of the "M" type backward wave oscillator as an rf generator for ECM equipment and due to the addition of advanced operational equipment needs, new requirements were imposed on the M-BWO's. These requirements as listed below;

1) Thermal frequency drift and transient time
2) Long life expectancy
3) Shock and vibration ruggedness
4) Mechanical interchangeability
5) Reduced cost of manufacture

were designed into, studied and evaluated under this manufacturing methods contract with great success. The work progressed rapidly due to the excellent design base achieved from previous work.

At the completion of the contract, all the important bands had been brought to a state of readiness to insure high quantity quality production as the need required it and the need did arise. As a direct result of this program Raytheon was able to, when contacted by the Air Force in November of 1962, gear up for quantity production and produce 1000 C-band tubes and deliver them ahead of the scheduled deadline of June 1963.

Phase I. REDESIGN AND REFINEMENT

1. Phase Objectives

Among the numerous objectives attained during the Phase I program, the following represent the most outstanding:

a. Smaller packages were designed to reduce the four tube types to minimum practical size and weight. Moreover, the tubes terminating in 7/8-inch coaxial type rf outputs (QKA851 and QKA852) were so designed that the rf terminations are located identically with respect to their mounting plates and electrical input connections to make them interchangeable with the QKA850 and QKA853 tubes (Band 1 and Band 5, respectively, of the compatible series). Meanwhile, the QKA855 and QKA857 were terminated in DR-19 waveguide, also located identically with respect to their mounting plates and electrical input connections whereby the tubes will be mutually interchangeable in their respective sockets.

b. The four tube types were adapted to have half-band sole tuning capabilities.

c. All tube types were redesigned to be cooled by DC-200 coolant. Frequency stability of these tubes was maintained from two minutes after application of the delay line current (transient time specification). In addition, frequency stability was achieved under specified thermal variations (thermal drift specification).

d. The subject tube structures were refined to insure withstanding "5G" cold vibration and "2G" operational vibration in three mutually perpendicular planes, from 5 to 1500 cps, under specified cycling conditions.

During the early Phase I period, work on the QKA851 and QKA852 was essentially devoted to problems of the delay line. On the basis of calculations of the natural frequency of vibration of the conventional straight finger, the decision was made to use a modified crown delay line for the QKA851. Similar calculations on the QKA852 straight finger revealed that the standard crown delay line would be more adaptable to this tube. Output transition systems for the QKA851-852 were evolved as well as adequate cooling designs, suitable electron guns, and thermally compensated magnets. Other basic assemblies were derived from modifications of existing Raytheon M-type backward oscillators. Vibration testing on essential parts and assemblies was conducted to insure over-all conformance to the vibration requirements. Tubes of each tube type were constructed, tested, evaluated and refined, while the electrical, mechanical and process specifications were brought to within 10% of completion. The final QKA851 and QKA852 tubes constructed during Phase I met all of the electrical requirements.

On the QKA855-857 program, early effort was directed toward devising and subsequently evaluating suitable output transition systems. Three outputs to unpressurized DR-19 waveguide were investigated on the QKA857, with the final choice being an "end fire" coaxial system, coaxial-to-ridge waveguide using a "flexible" alumina window. The choice of this system was prompted by the reproducibility of the electrical and mechanical characteristics. On the QKA855, of the two output systems to DR-19 unpressurized waveguide which were investigated, the choice (for the same reasons) was given to a tapered impedance single-to-double ridge waveguide, where the single ridge was utilized as the first finger in the delay line; a flexible window similar to that of the QKA857 was employed. Standard crown delay lines were developed for both tube types, as well as cooling systems, thermally compensated magnets, electron guns and remaining sub-assemblies. Tubes of

each type were tested, evaluated and refined, while the electrical, mechanical and process specifications were brought to within 10% of completion. Final QKA855 and QKA857 tubes tested during this phase met all electrical requirements. With all objectives having been attained for the QKA851, QKA852, QKA855, and QKA857, approval was obtained from the contracting agency to proceed with the Phase II program.

2. QKA851 (Band 2, 1300-1850 Mc)

a. Delay Line

A suitable delay line for the QKA851 was determined by adjusting the delay line parameters of the QKA657 prototype tube to increase the tuning range while maintaining consistency of heat dissipation, coupling impedance and bandwidth. Across the range of interest (1300-1850 Mc), $|c/v|$ figures of between 15 and 25 were predicted to establish suitable values for the finger length (ℓ) and delay line pitch (p) by means of the parallel plate approximation

$$c/v = \frac{\ell}{p} - \frac{\ell + p}{p}$$

A computation of the theoretical natural frequency of vibration of the straight finger length, obtained from the above approach, disclosed that the frequency would be less than 1500 cps, which is the maximum frequency to which the tube is to be subjected and which it must withstand during vibration tests. Moreover, a construction featuring the conventional crown arrangement with this finger length would necessitate using an extremely wide magnet gap, which introduces bowed magnetic fields and prevents the attainment of a uniform flux density in the center of the interaction space. For these reasons, the decision was made to employ a modified crown delay line in which the natural frequency of vibration of the fingers is above the 1500 cps minimum and, in addition, the theoretical length of the finger computed from the above relationship is preserved and the smaller magnetic gap is used.

Backwall spacing, radial height, finger spacing and other delay-line parameters were derived by frequency scaling from values used in other Raytheon M-type backward-wave oscillators. The active and attenuation lengths of the delay line were also determined by frequency scaling, and starting currents were computed to ensure that these lengths were well within the desired limits.

Analogue conductance measurements of the delay line were made to arrive at approximate values for the cutoff frequencies and to be able to draw up a dispersion curve for the delay line. An enlarged cross section of a portion of the delay line was applied to resistive paper with silver paint, and a voltage was placed on one of the fingers relative to the other elements.

By balancing the voltages on adjacent fingers, backwall and sole by means of resistances placed in the circuit, a measurement of the conductance could be obtained. From these values of conductance, the electrostatic coefficients per unit length could be determined, and the c/v values for drawing up the dispersion curves could be obtained by the usual bar-line formulae. This curve is shown in Figure 1.

The QKA851 delay line features two transformer sections. The first provides an impedance transition from the output to the active portion of the line, and the second transformer section matches the active and attenuation regions of the line. In each section, a gradual impedance transition is effected by a variation in finger spacing.

A parallel investigation was undertaken to improve manufacturing techniques using modified QKA851 crowns. Investigation was made into an improved brazing technique which would provide for better alignment of the delay-line fingers and would insure savings in cost and manufacturing time. Tube No. 009 constructed during Phase II with the modified crowns produced by this new technique met all of the electrical requirements.

b. Output

The basic design of the QKA851 output assembly is an adaptation of that used on the QKA657 prototype tube. Early in the Phase I program, cold test loads for matching the QKA851 outputs were developed, and these loads were subsequently used through the remainder of the program to provide checks on the output transition system. Little difficulty was encountered in

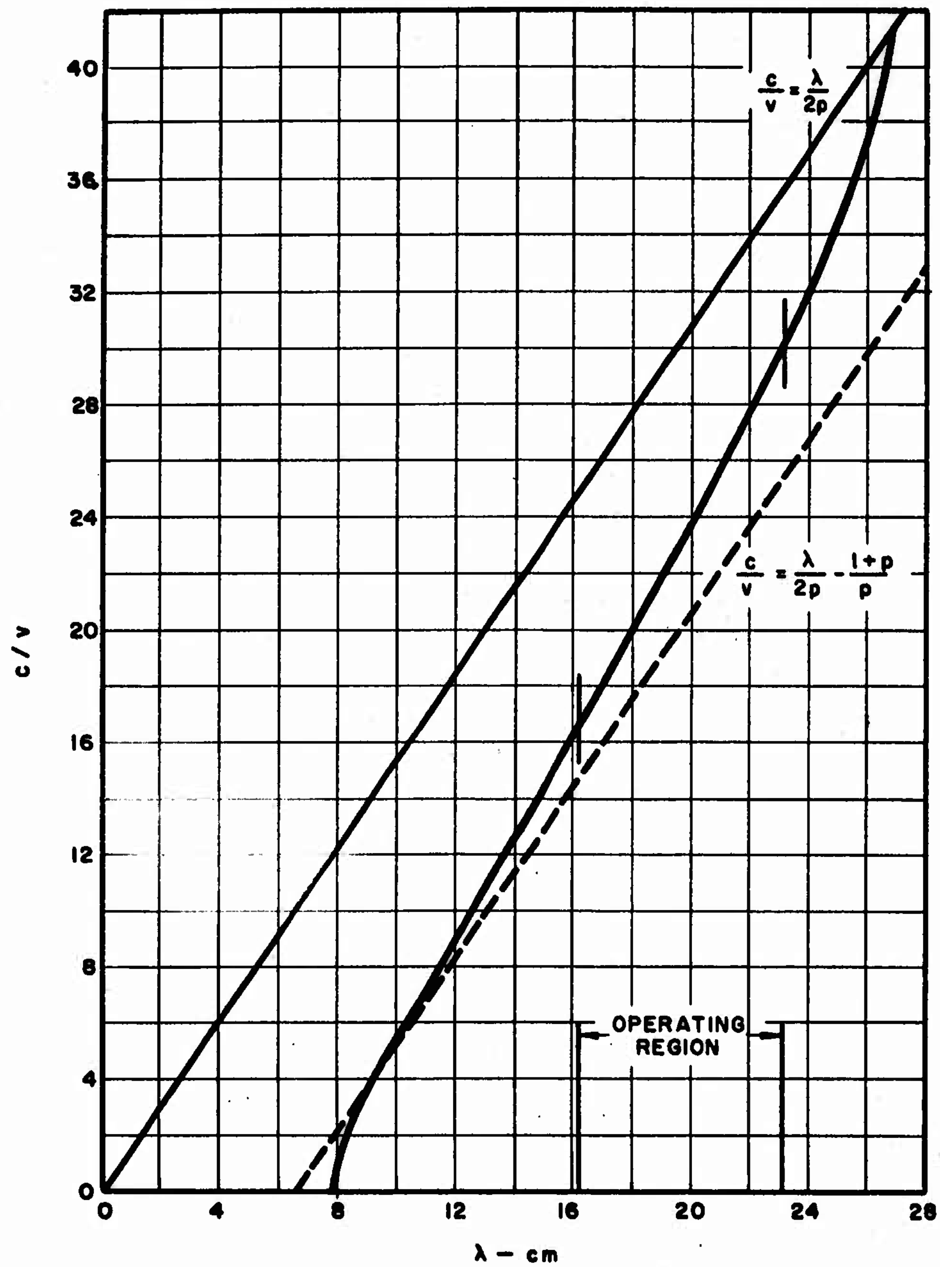


FIGURE I QKA851 c/v vs λ CURVE OBTAINED FROM RESISTANCE PAPER MEASUREMENTS

matching the QKA851 output to the modified delay line (described in the previous topic). Figure 2 shows a curve representing typical cold test performance of a QKA851 in which percent of voltage reflection is plotted against frequency over the range of interest, and indicates that the peak reflection obtained from this transition system is about twenty percent.

Figure 3 is a photograph of the output assembly.

c. Magnet

The delay line chosen for the QKA851 used an air gap small enough to allow the QKA853 magnet to be adapted to the QKA851 application. The stabilized level of magnetic induction in the air gap was more than adequate for proper operation of the tube. Compensated and uncompensated magnets using the designed pole pieces to focus the magnetic field over the interaction area were subjected to temperatures from $-55^{\circ}C$ to $+100^{\circ}C$, and flux measurements were taken at various temperature intervals. Similar measurements were taken for the QKA852, which utilizes the same magnet and gap; Figure 16 on page 30 shows a curve of the temperature vs gauss with and without compensation for that tube. Magnetic induction readings across the gap were also taken by a rotary coil probe to assure a peaking of the field over the interaction space.

Figure 4 shows the QKA851 magnets on a final package tube.

d. Electron Gun and Optics

The QKA850 electron gun was scaled for use in the QKA851. By making modifications and adjustments in the configuration and position of the gun elements, the optics for optimum tube performance were obtained. Moreover, the entire optics assembly was so designed that many of the gun parts employed on the QKA850 production tube could be utilized. In this way,

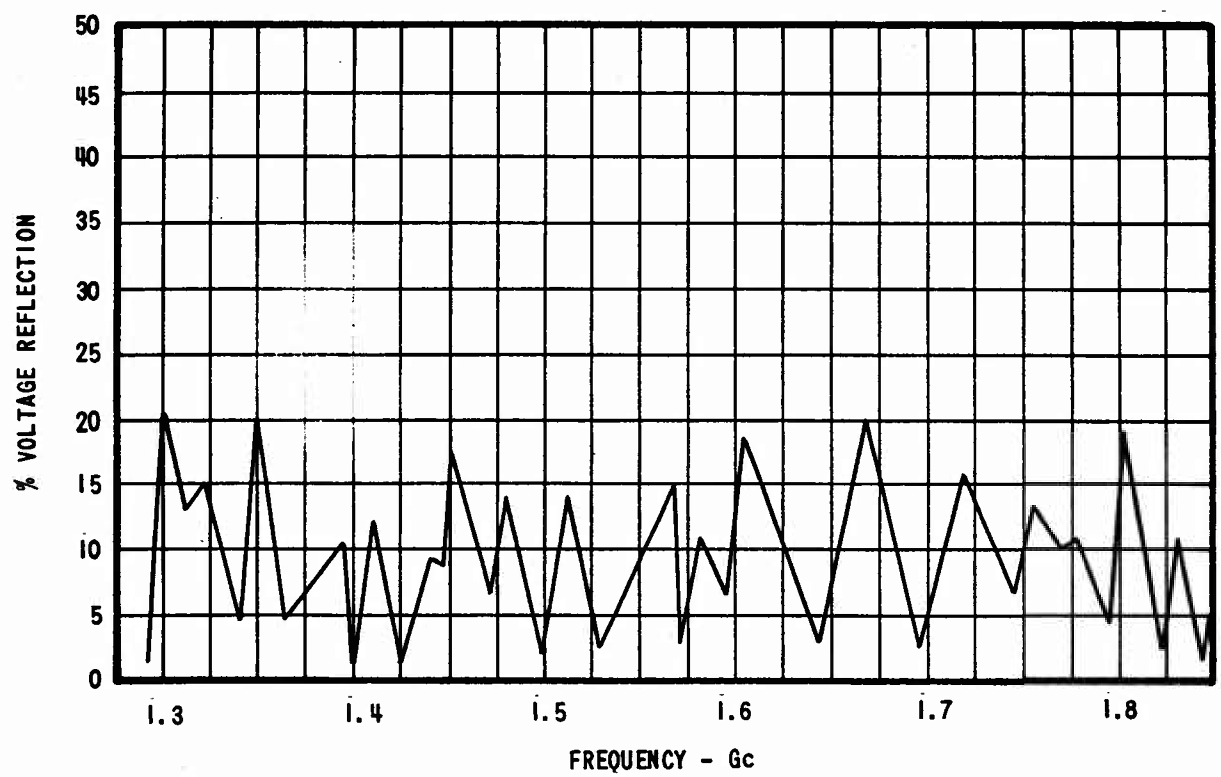


FIGURE 2 QKA 851 - TYPICAL COLD TEST PERFORMANCE

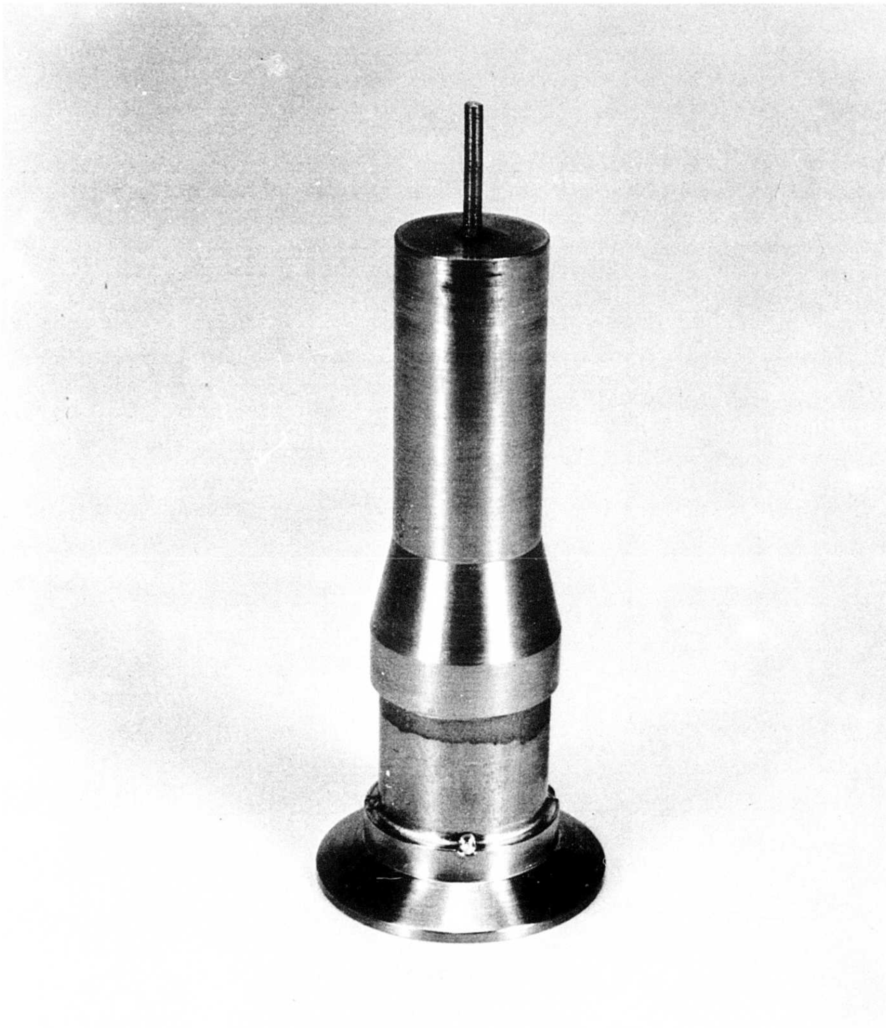


FIGURE 3 OUTPUT ASSEMBLY - QKA851

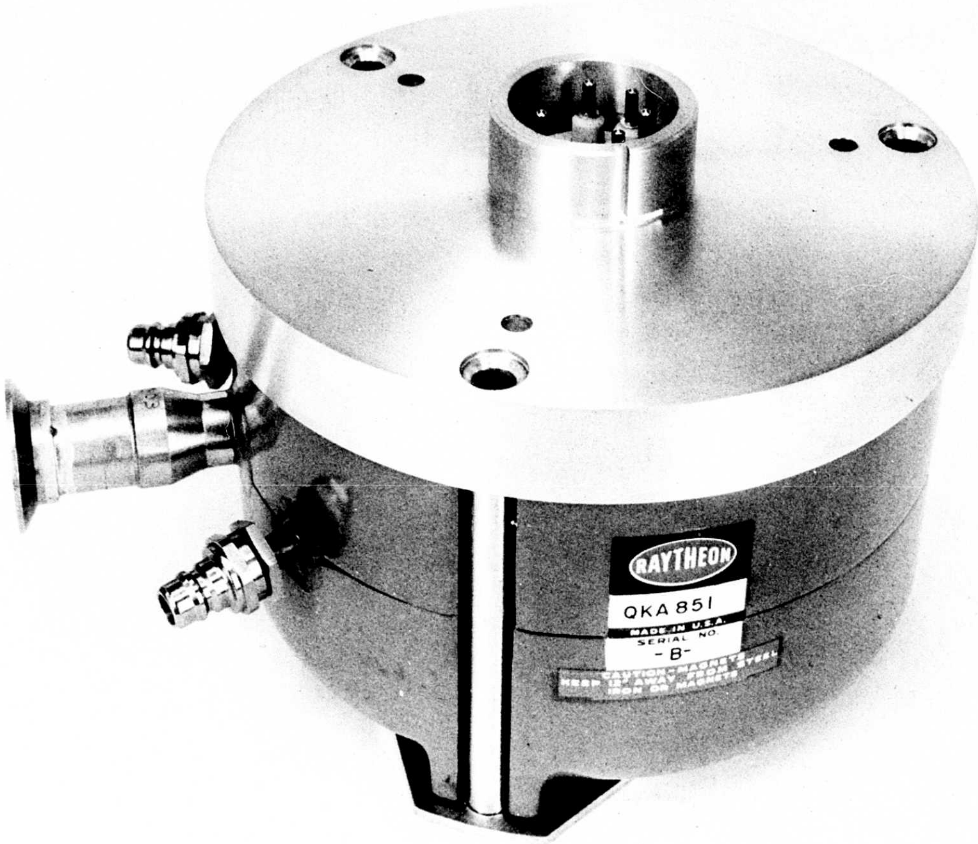


FIGURE 4 PACKAGED TUBE - QKA851

cost reduction could be achieved for future gun parts, and, at the same time, existing production tooling could be used to produce the basic electron gun sub-assemblies.

Vibration testing of the gun-sole assemblies was conducted under the conditions stipulated in the specifications. Major resonances were dampened by appropriate adjustments in the support elements and by major modifications in the supporting structure.

Figure 5 shows the QKA851 electron gun assembly and components. Figure 6 shows this gun mounted on the sole (Gun Sole Assembly).

e. Electrical Results

During this phase, six tubes were electrically tested. Three of these tubes met all of the power requirements, while the other three had border-line power at only one test point. The final tube constructed during this period met all of the electrical requirements and served as the prototype for initial models built during the Phase II program. Figures 7 through 9 show the electrical performance of this final model. Figures 8 and 9 represent the 300 ma and 200 ma (respectively) half-band sole tuning data in which power output is plotted against frequency. Figure 7 shows the 300 ma anode tuning data in which power output is plotted against frequency.

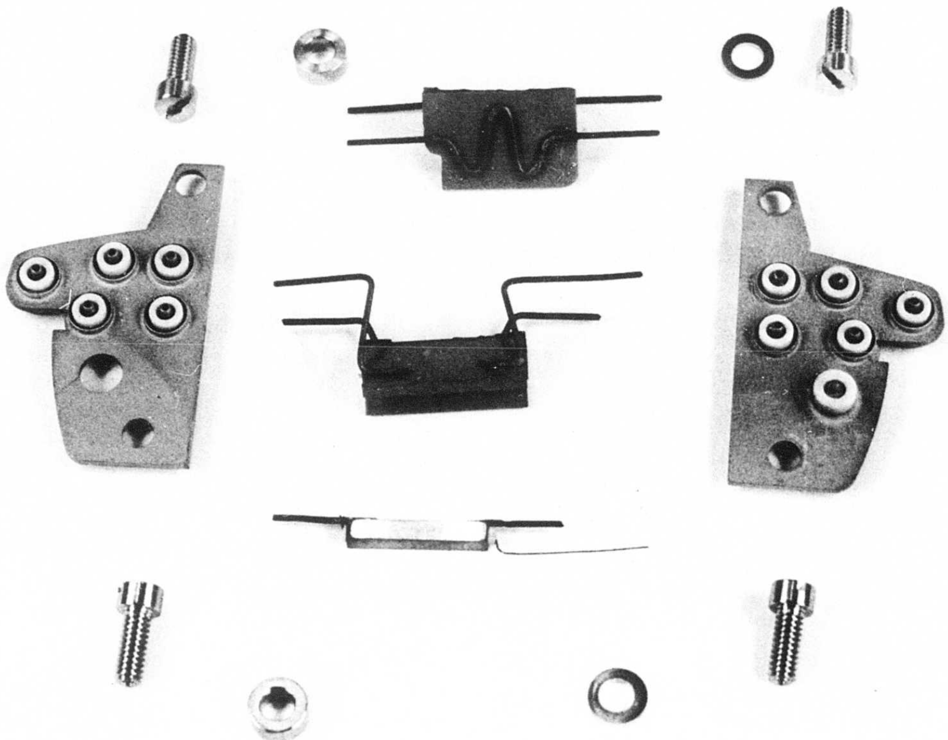


FIGURE 5 GUN ASSEMBLY COMPONENTS - QKA851

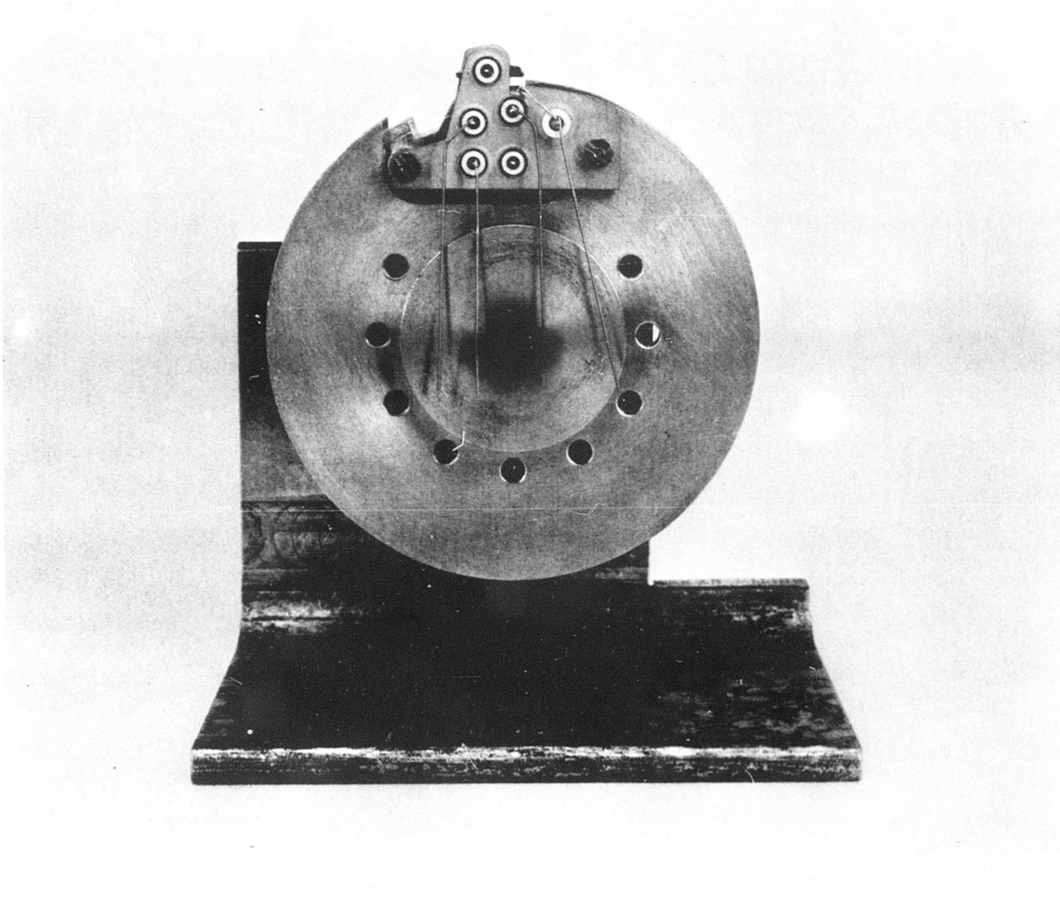


FIGURE 6 GUN SOLE ASSEMBLY - QKA851

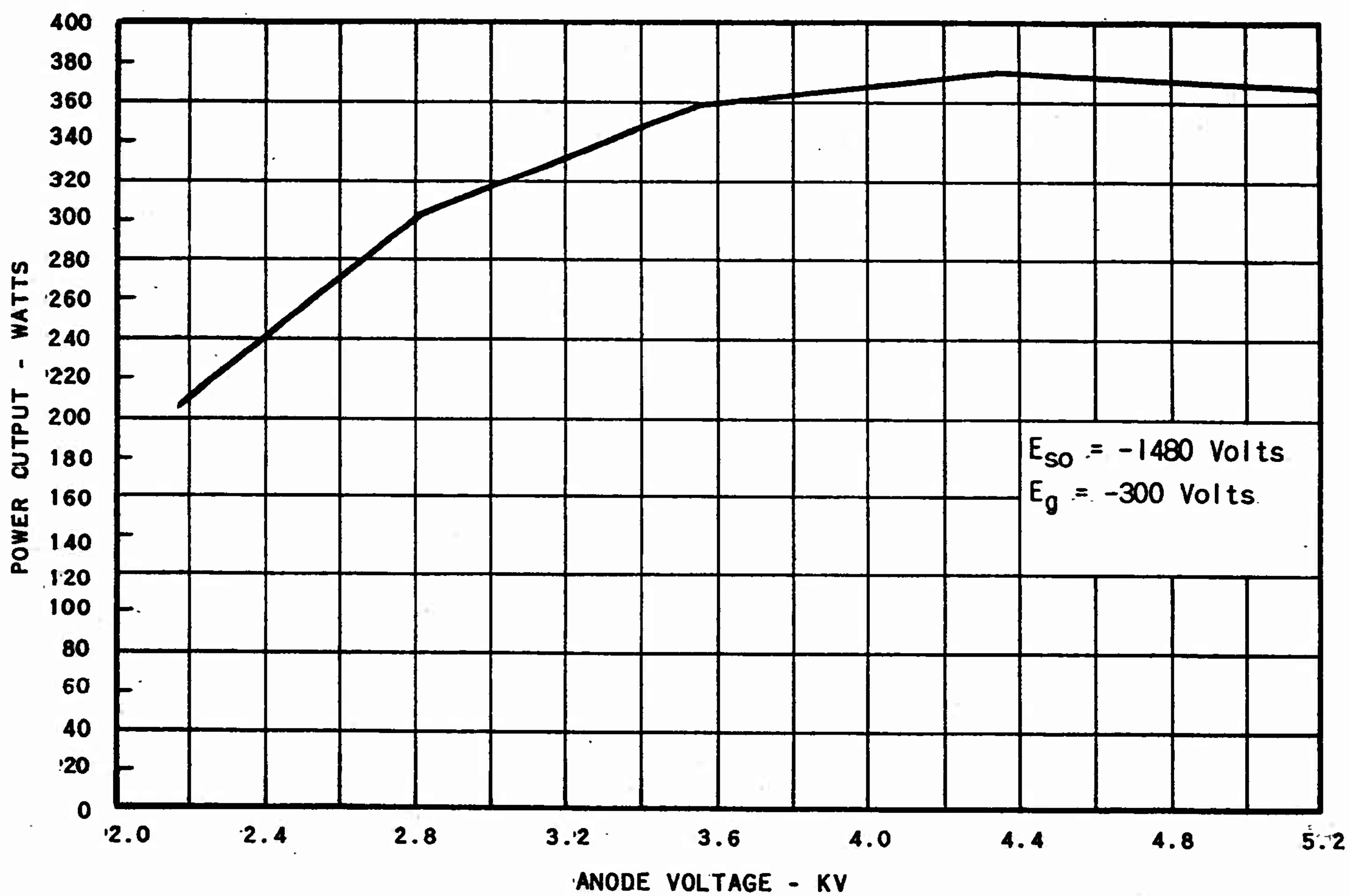


FIGURE 7 OKA851 TUBE "F" ANODE TUNING
POWER OUTPUT vs ANODE VOLTAGE 1300-1850 Mc

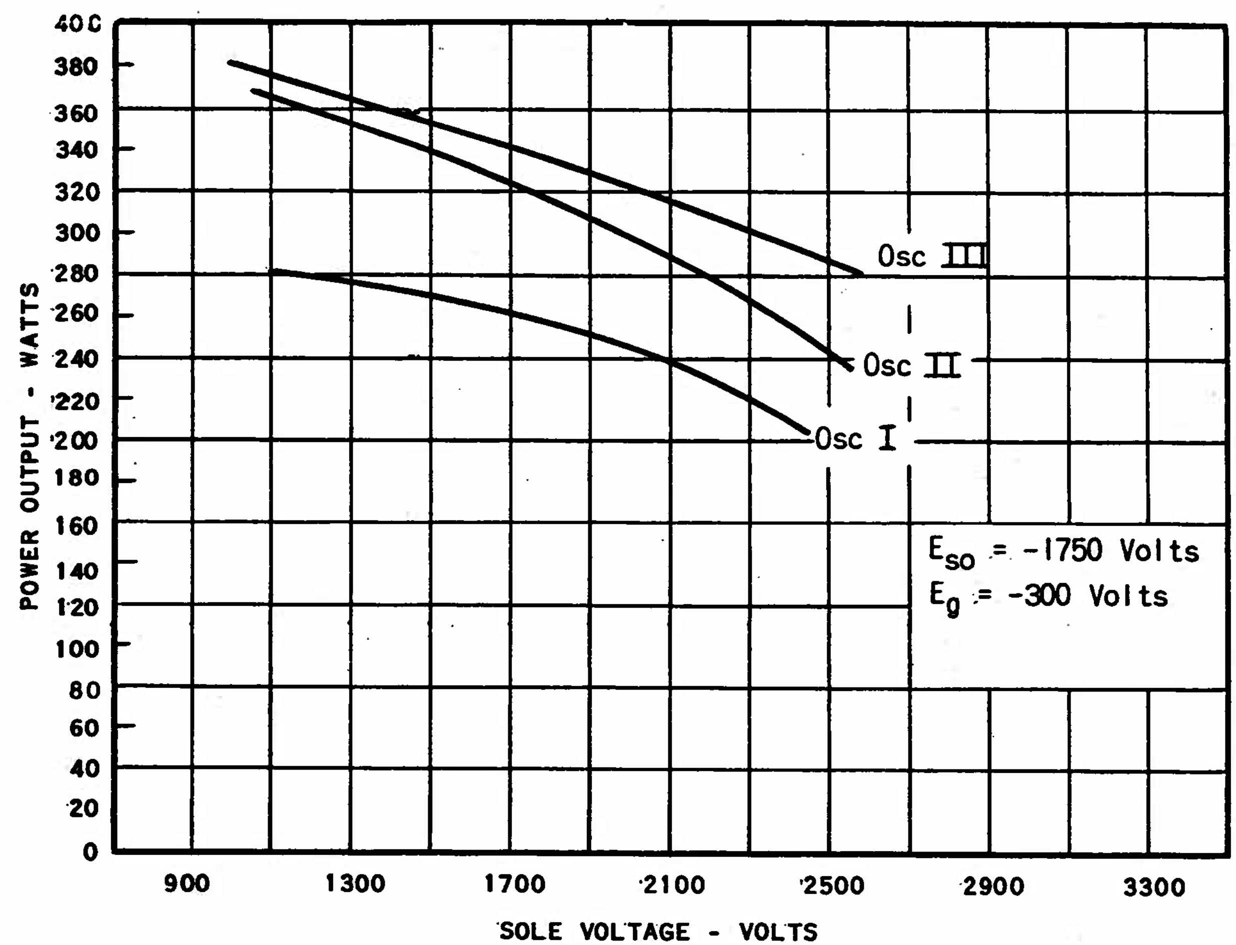


FIGURE 8 QKA851 TUBE "F" HALF BAND SOLE TUNING (300mA)
POWER OUTPUT vs SOLE VOLTAGE

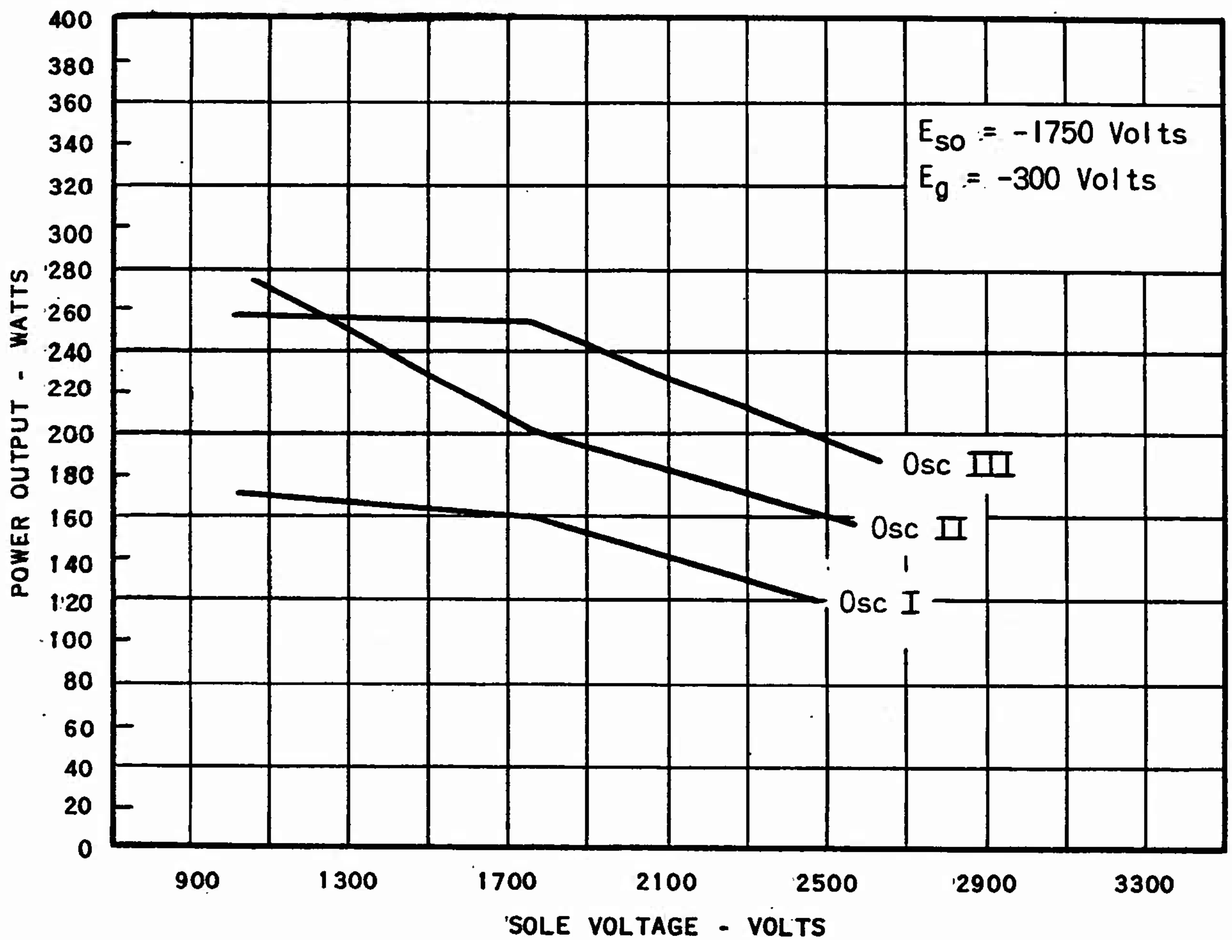


FIGURE 9 QKA851 TUBE "F" HALF BAND SOLE TUNING (220mA)
POWER OUTPUT vs SOLE VOLTAGE

3. QKA852 (Band 3; 1800-2550 Mc)

a. Delay Line

To determine a suitable delay line for the QKA852, the delay-line parameters of the QKA658 were adjusted to increase the tuning rate and to maintain consistency of heat dissipation, coupling impedance and bandwidth. Values for the finger length (ℓ) and the pitch (p) were determined, as for the QKA851, by predicting $|c/v|$ of between 15 and 25 across the frequency band and by utilizing the familiar parallel plate approximation. Other delay-line parameters were scaled from existing Raytheon M-type backward-wave oscillators. Calculations of the zero mode and T-mode cutoff were obtained from the customary relationships by bar-line analysis (making use of the parallel plate capacitance formulae), and were found to be well outside the frequency range of the tube. The length of the active delay line was scaled from the QKA853 and QKA658, and starting currents were computed to confirm the values for length obtained.

A dispersion curve was made by taking analogue conductance measurements of a simulated delay line applied to resistance paper by silver paint. Figure 10 shows a curve of the $|c/v|$ plotted against frequency obtained from the resistance paper measurements. The operating region of the tube is seen to be well within the cutoffs obtained from the experiment.

The QKA852 delay-line finger was found suitable for use in the standard crown delay line. Calculation of the resonant frequency for the derived finger length was made, and it was found that the frequency exceeded 150 cps.

The QKA852 delay line consists of both an output transformer and an attenuation transformer section. In the attenuation section, the pitch of the line is decreased so as to increase attenuation by providing closer spacings and more attenuation length. Because of these two transformers (and the accompanying change in pitch), it was necessary to utilize a pair of hobs to produce the interdigital line.

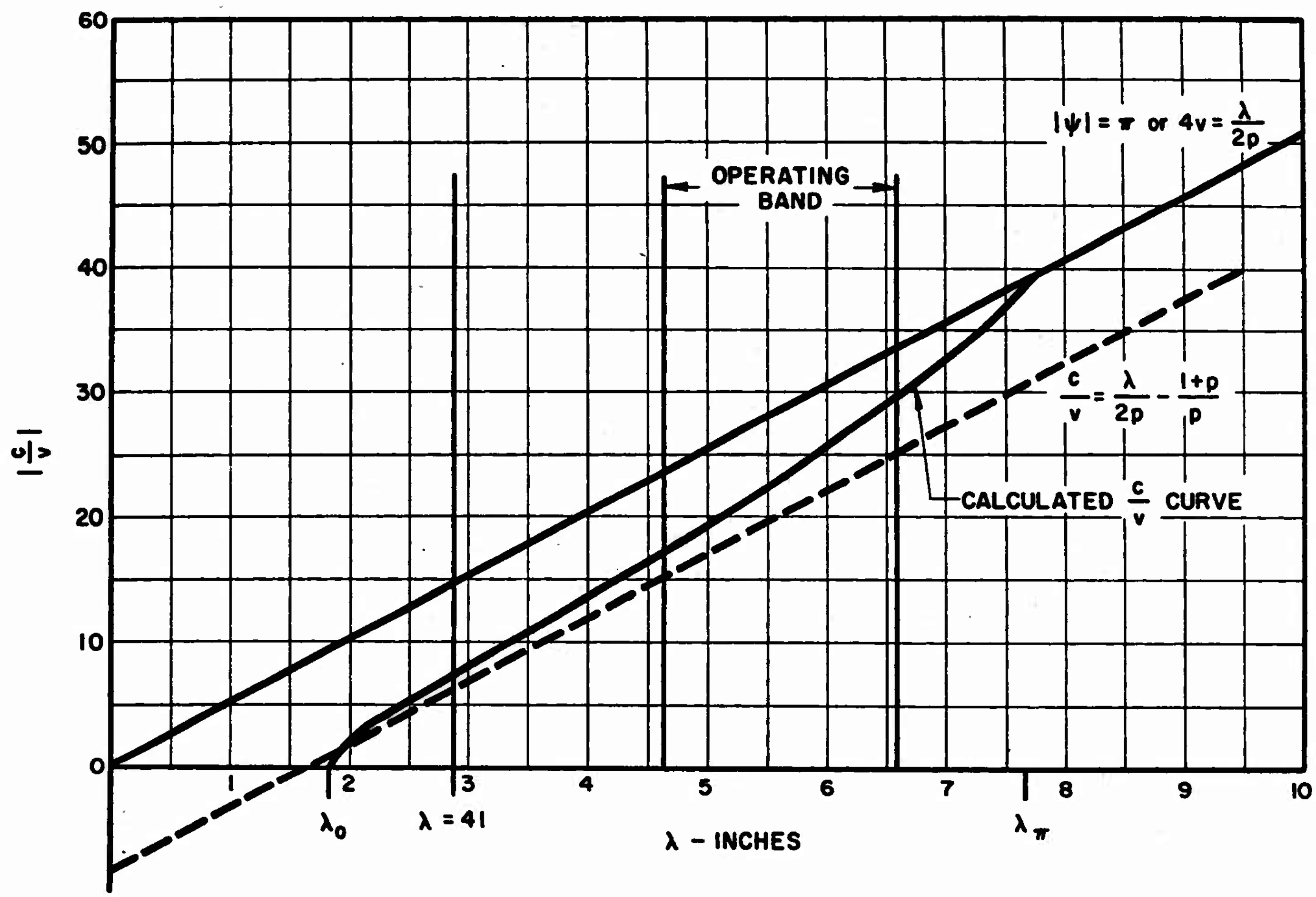


FIGURE 10 QKA852 THEORETICAL c/v vs λ CURVES BASED UPON ANNALOGUE RESISTANCE READINGS

Vibration testing of the delay-line cylinder assembly was conducted at an early stage, and it was observed that no major resonances were being generated by the structure. Later in the program, to improve the coupling between the output and the line, and,thereby, to better the tube performance, capacitance was added to the match by increasing the finger length by .017 inch. Vibration tests performed on the modified delay line structure showed no outstanding resonances below 1500 cps.

b. Output

Because of the objective requirement that the QKA850, QKA851, QKA852 and QKA853 outputs be positioned identically with respect to the mounting plate, a problem arose of matching the output transition system to the line. This condition resulted from the difficulty in attaining an impedance in such a short electrical length of line and also from the fact that the placement of the output demanded that the coupling of the output coaxial line be not to the extremity of the first interdigital finger but to a point approximately two-thirds of the length of the finger from its base. Measurements indicated that there were both inductive and resistive components which had to be compensated. This was accomplished by making adjustments of the rf center conductor to a point of higher impedance and by loading the output finger. Figure 11 shows a cold test performance for a typical tube constructed during Phase I.

During the latter part of the program, it was found advantageous to provide additional loading of the delay line to further improve the coupling. This modification succeeded in reducing reflection peaks on the average by approximately seven percent and substantially enhanced tube performance. Figure 12 shows the improved cold test performance.

Vibration tests of output-cylinder assemblies were conducted to observe resonances within the vibration range of 5 to 1500 cps. Several minor disturbances were noted at the 5-G vibrational level. To reduce potential disturbances resulting from these resonances, the output transition system was reinforced and the coupling interdigital finger was brazed to the center conductor of the output.

Figure 13 is a photograph of the output-cylinder assembly for the QKA852.

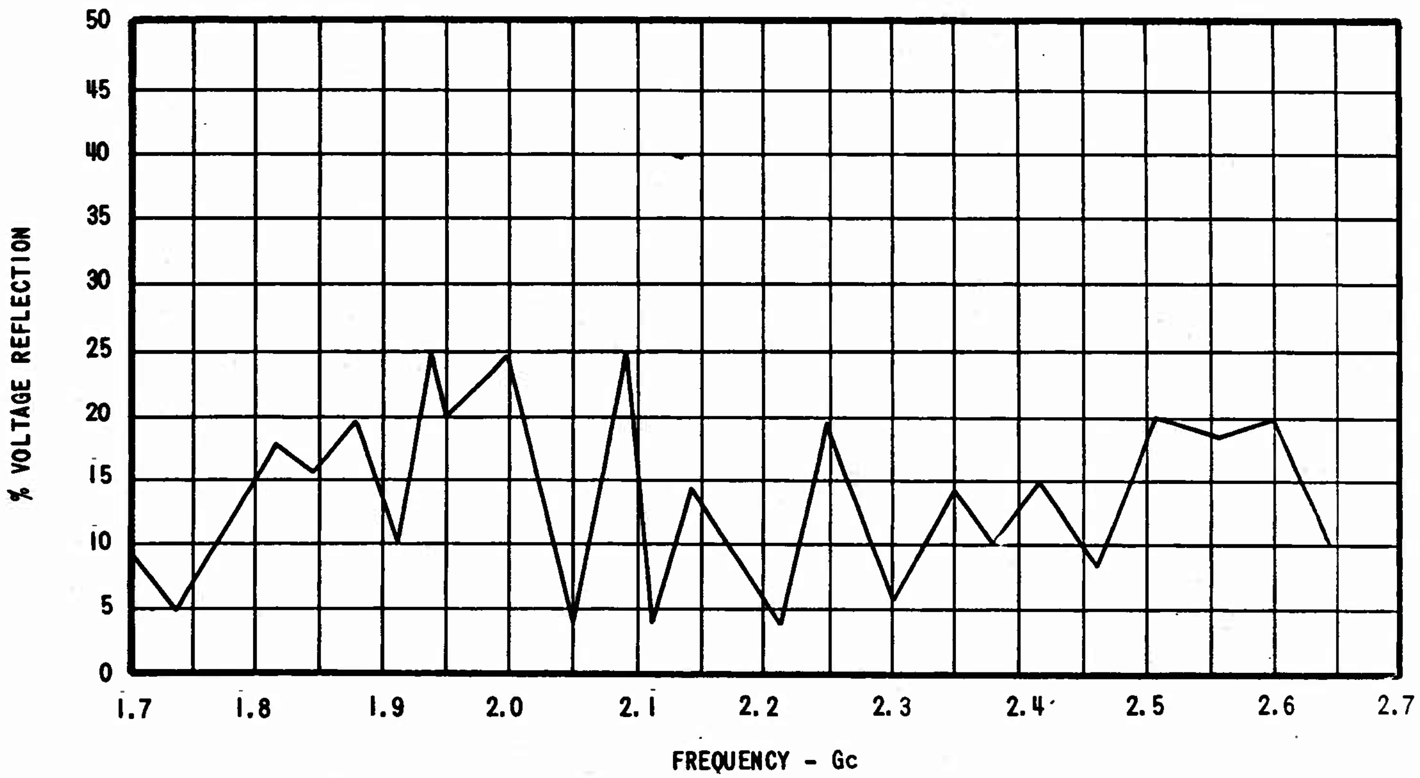


FIGURE 11

QKA 852 - TYPICAL COLD TEST PERFORMANCE

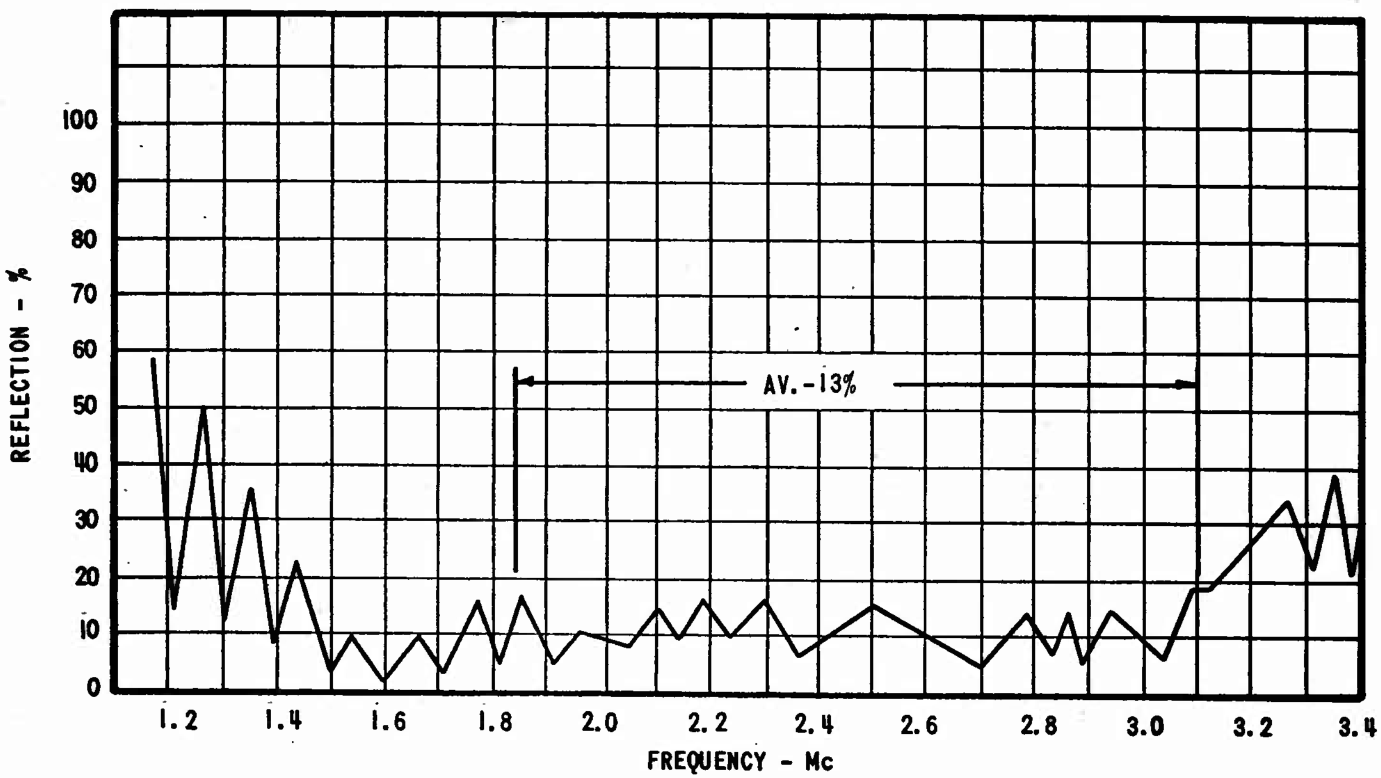


FIGURE 12 QKA 852 NO.014 COLD TEST REFLECTION vs. FREQUENCY (MOUNT STAGE)

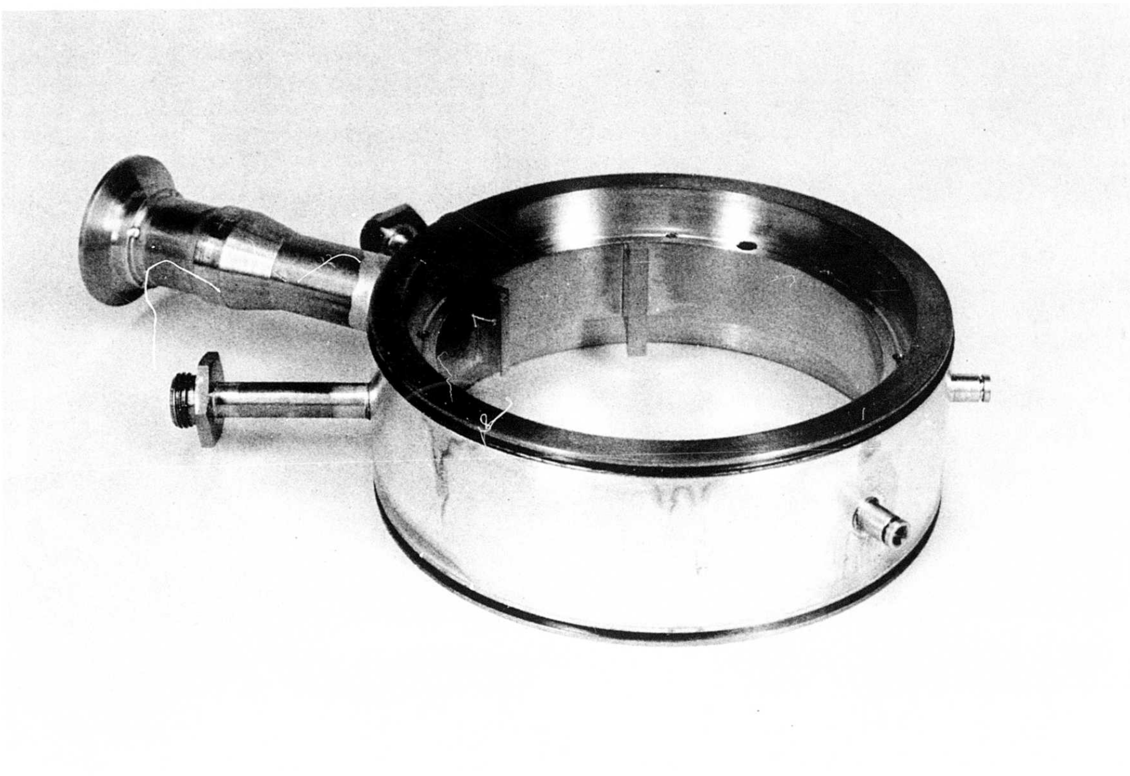


FIGURE 13 CYLINDER OUTPUT ASSEMBLY - QKA852

c. Electron Gun and Optics

An electron gun based upon that used in the QKA853 M-type backward-wave oscillator was designed for operation in the QKA852. Achievement of the optics for optimum tube performance was obtained by making modifications in the configuration and position of the gun.

Early in the program, sole-gun assemblies were subjected to the specified vibration levels from 5 to 1500 cps in three planes. Major resonances were detected and dampened by modifications in the supports of the gun elements. Testing was facilitated by the use of a stroboscopic light (which was synchronized with the vibration frequency and was so adjusted that its frequency varied up to three cps from the driver frequency). By employing this technique, the magnitude and frequency of the natural resonances in the gun structure could be detected visually. Several assemblies containing variations in gun construction were tested to establish a final design capable of withstanding the specified vibration tests.

Figure 14 is a photograph of the electron gun components and Figure 15 is a photograph of the gun assembly mounted on the sole.

d. Magnets

The QKA852 magnets are identical to those used on the QKA851 tube. The stabilized level of the magnetic induction at the center of the gap was more than adequate for this purpose.

Pole pieces designed to focus the field over the interaction space were employed in suitable magnets, and magnetic induction readings were taken across the gap to confirm the design values. Compensated and un-compensated magnets were subjected to temperatures from -55°C to +100°C and flux measurements were taken at various temperature increments. The results obtained are shown in Figure 16 and are similar to those measured on the QKA851 magnets.

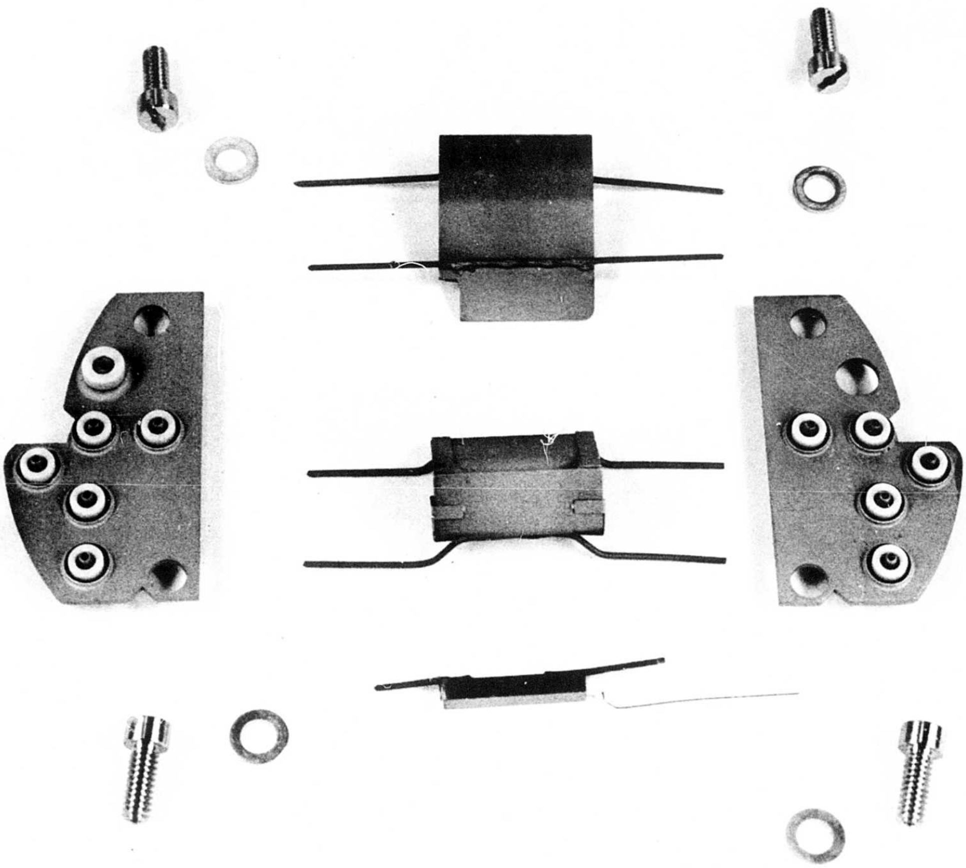


FIGURE 14 GUN ASSEMBLY COMPONENTS - QKA852

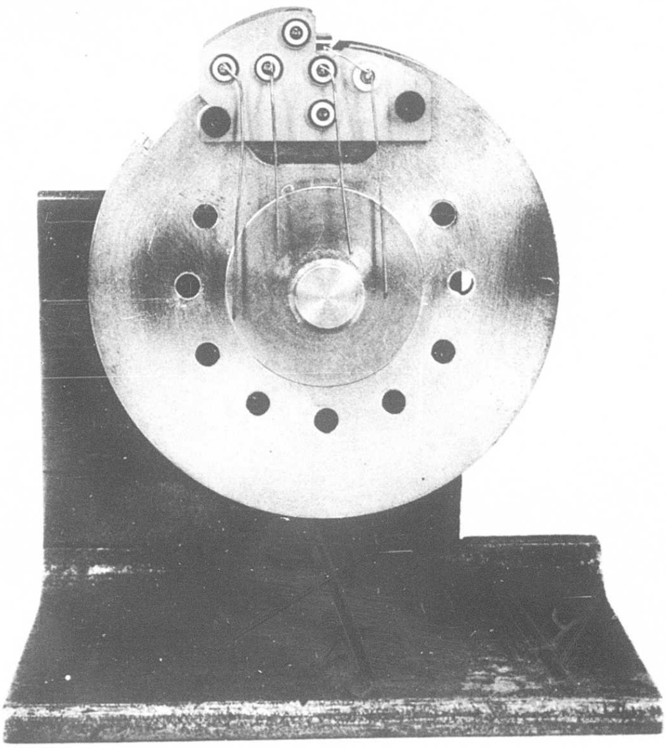


FIGURE 15 GUN SOLE ASSEMBLY - QKA852

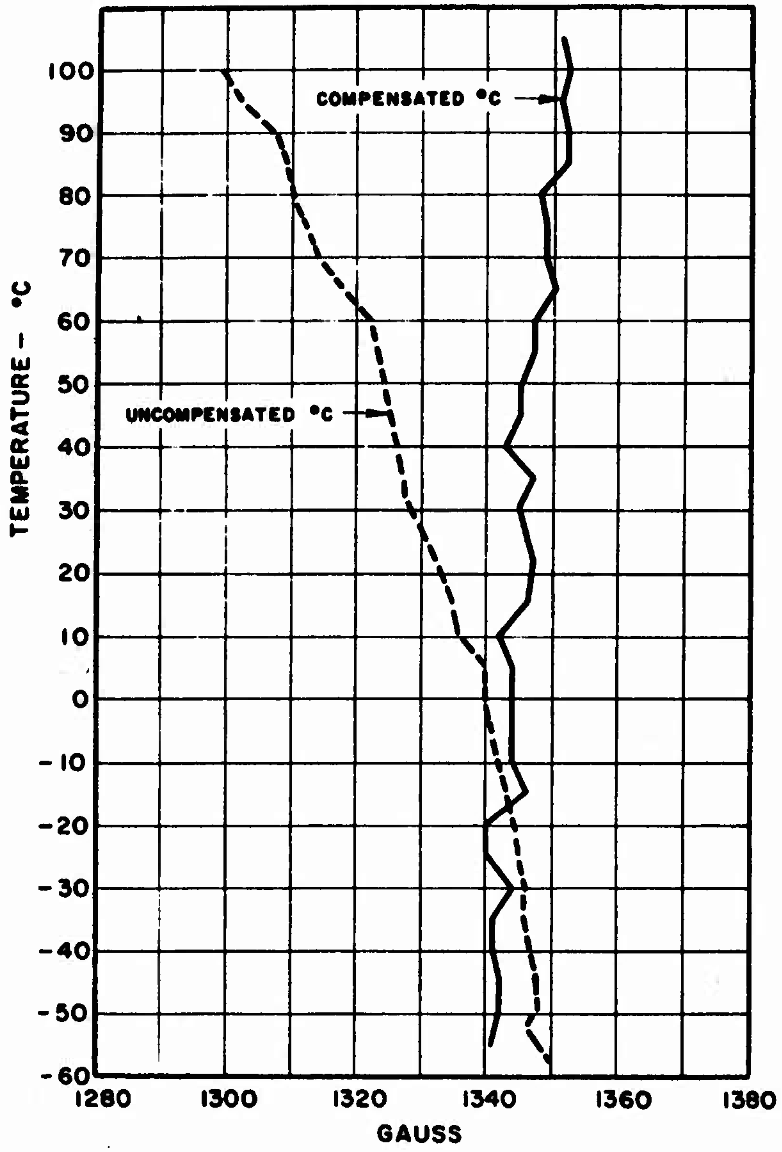


FIGURE 16 QKA852 UNCOMPENSATED AND COMPENSATED TEMPERATURE vs GAUSS

Tube data taken at a later time suggested that improved tube performance could be obtained by adjusting the distribution of the magnetic field flux line across the interaction region. This was accomplished by adjusting the diameters of the pole pieces until the desired magnetic field was obtained between sole and delay line. This modification made a marked improvement in tube performance.

Figure 17 is a photograph of the packaged QKA852, showing the magnets used.

e. Electrical Results

During the Phase I effort, seven QKA852 tubes were electrically tested. The results showed that consistent improvements in the electrical characteristics had been obtained as a result of modifications in the delay-line parameters and adjustments incorporated into the tube optics. Whereas the first tube constructed during the program had power failures at several operating points, the seventh model met all of the required electrical specifications. Because of the promising results obtained from the final tube, it was used as the prototype for the initial models fabricated during the Phase II program. Figures 18 through 20 show the electrical performance of this tube. Figure 19 and Figure 20 represent the 300 mA and 220 mA (respectively) half-band sole tuning data in which power output is plotted against frequency. Figure 18 shows the 300 mA anode tuning data in which power output is plotted against frequency.

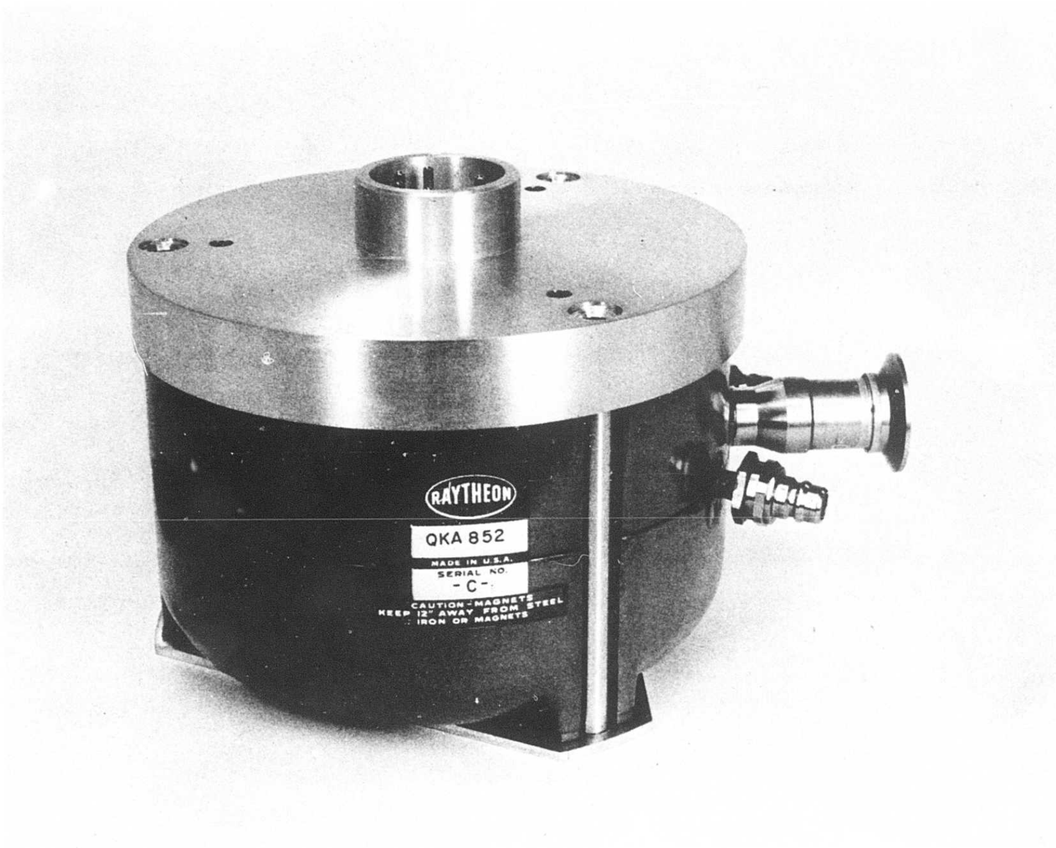


FIGURE 17 PACKAGED TUBE - QKA852

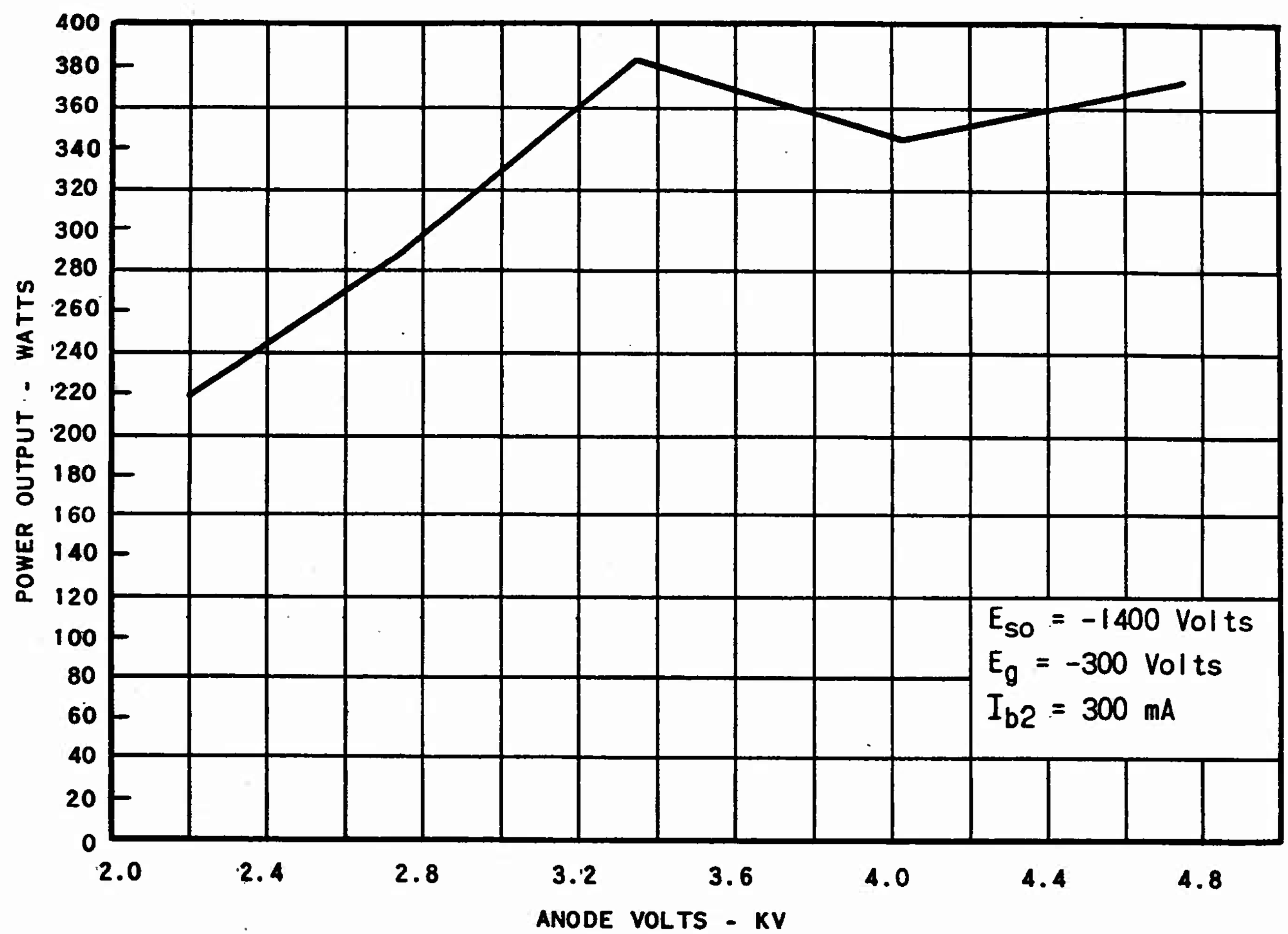


FIGURE 18 QKA852 TUBE "G" ANODE TUNING
POWER OUTPUT vs ANODE VOLTAGE 1800-2550 Mc

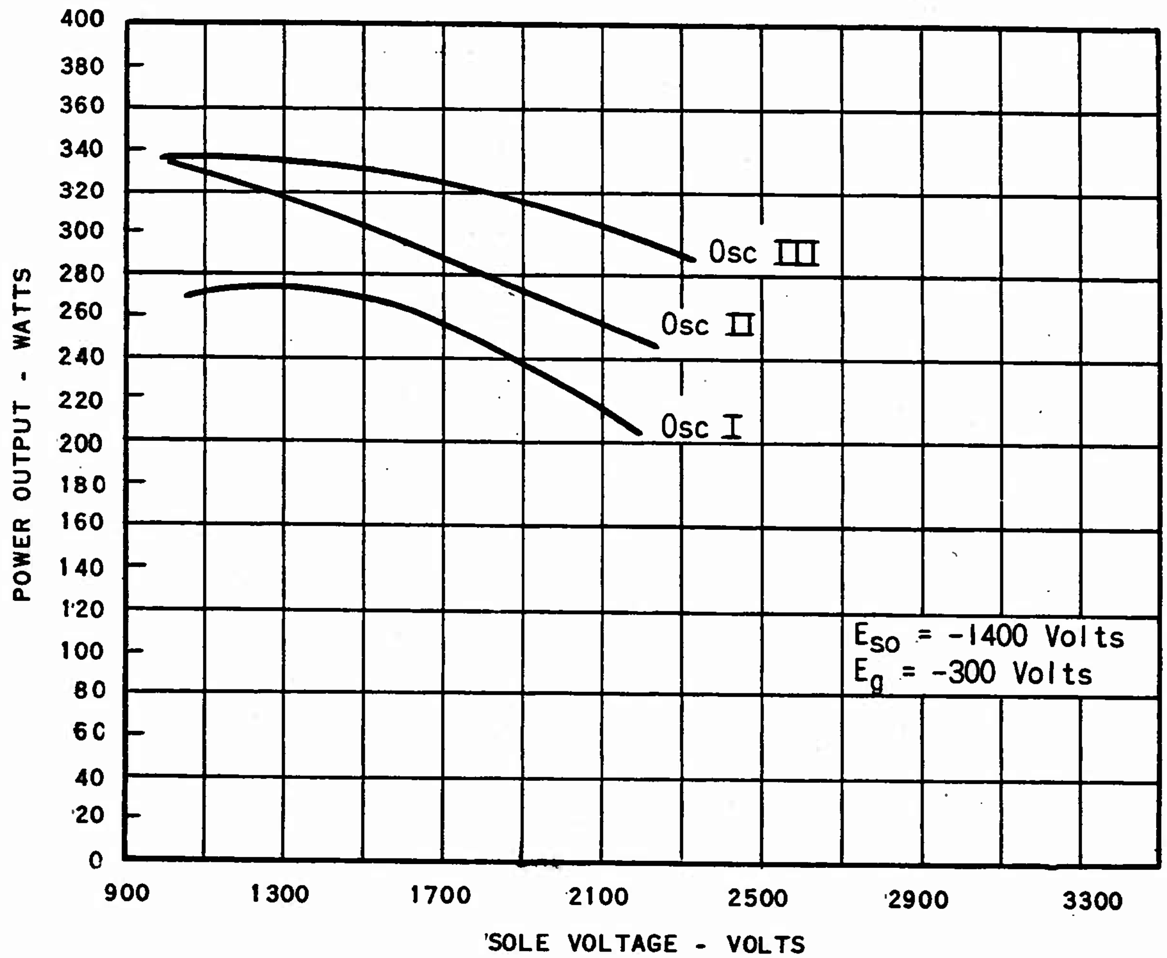


FIGURE 19 QKA852 TUBE "G" HALF BAND SOLE TUNING (300mA)
POWER OUTPUT vs SOLE VOLTAGE

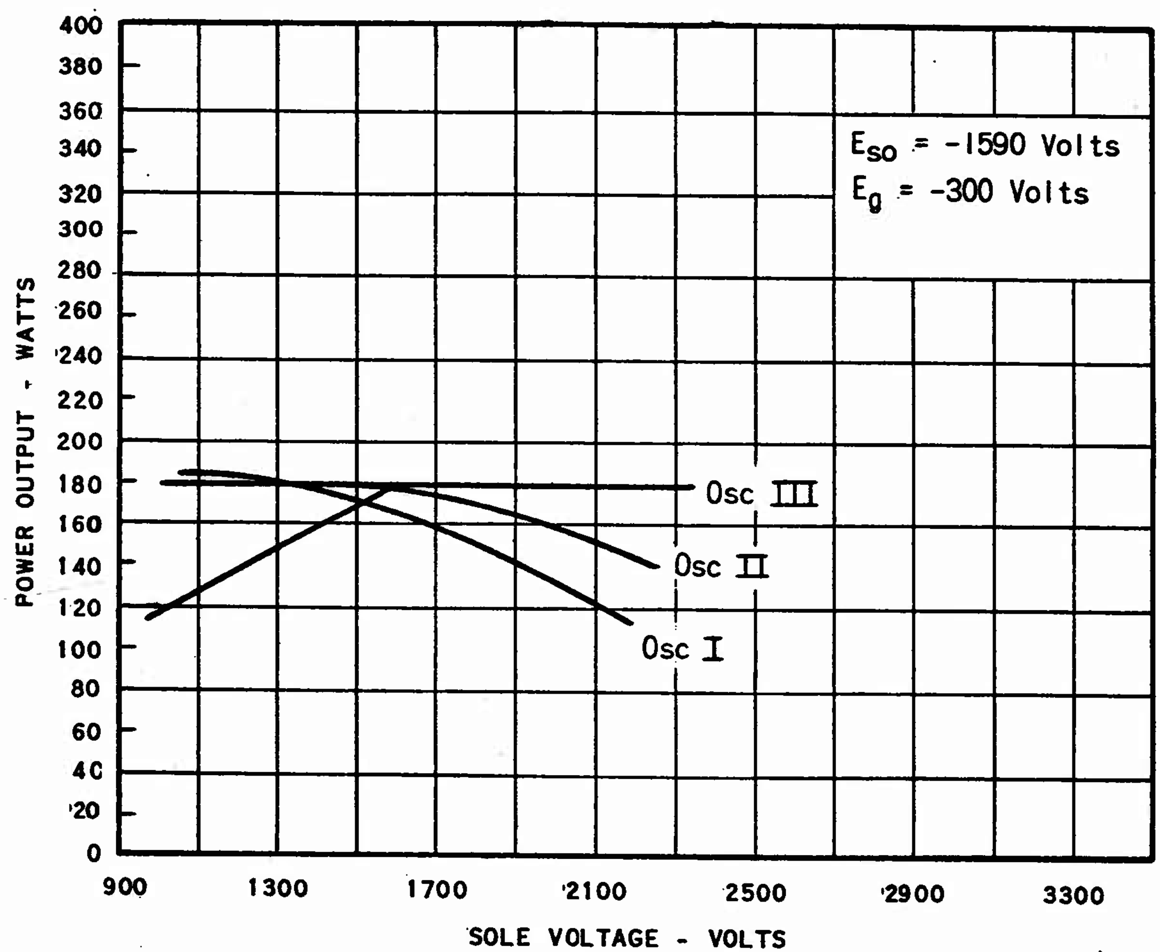


FIGURE 20 QKA852 TUBE "G" HALF BAND SOLE TUNING (220mA)
POWER OUTPUT vs SOLE VOLTAGE

3. QKA855 (Band 6; 4800-6550 Mc)

a. Delay Line

The QKA855 delay line dimensions are identical to those of the prototype QKA660 except that the interdigital finger length had to be reduced to increase tuning. A study of the dispersion characteristics of this delay line indicated that anode voltage limits would not be exceeded in half-band sole tuning operation and that frequency cut-offs would be well within the extremes of the band.

It was found that the coupling impedance of the delay line incorporated into the first tubes proved to be too low, whereas the dissipation qualities of the same delay line were more than adequate. The ensuing tubes featured a higher impedance delay line with a corresponding increase in the performance characteristics.

Many of the problems connected with the QKA855 delay line are similar to those encountered in the QKA857 and are discussed in the appropriate QKA857 section. Instrumentation to insure accuracy of the QKA855 crowns was utilized to eliminate many of these problems.

b. Waveguide - Output System

A great deal of time was devoted to the development of an rf output system for the QKA855. The requirements of the system are as follows:

1. Compatibility with DR-19 waveguide.

2. Ability to withstand 5-1500 cps vibration at 5G and 15G shock impulse.

3. Not to extend more than 3.750 inches from the axial center line of the tube and to be centered 2.000 inches below the surface of the mounting plate. These requirements were met. The VSWR of the waveguide and window portions of the system presented a negligible amount of mismatch to the propagating rf wave.

(1) Output Window Assembly

Two distinctly different types of output window were evaluated. These are shown in Figure 21.

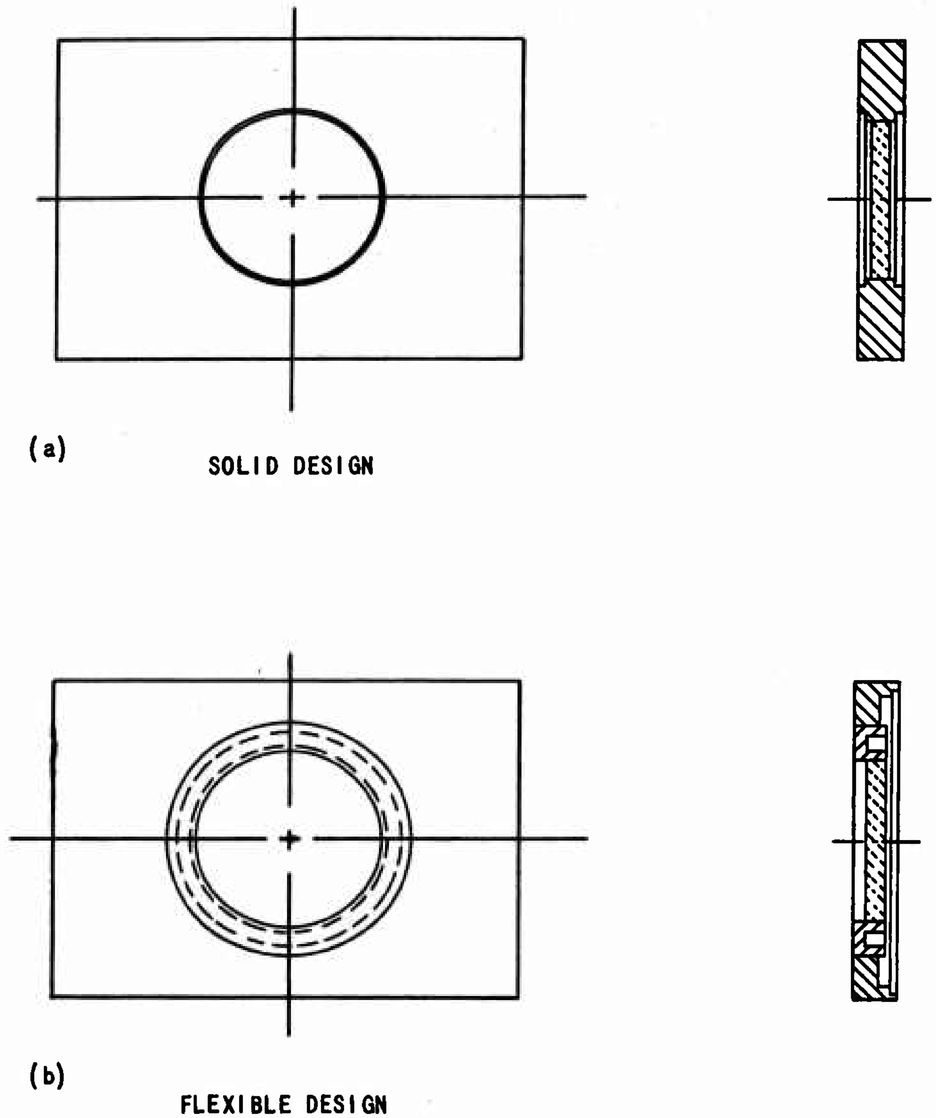


FIGURE 21 QKA 855 OUTPUT WINDOW ASSEMBLY

(a) Flexible Design (Figure 21b) - This particular design permits a nominal amount of thermal expansion with a minimum amount of mechanical restraint. The U-shaped channel is fabricated to insure a reasonable balance between thermal flexibility and rugged mechanical design.

(b) Solid Kovar Design (Figure 21a) - In this design, the metalized and plated ceramic disc is copper brazed into the solid flange. At room temperature, the ceramic disc flange assembly is a snug fit. At the melting temperature of copper, the flange will have expanded more than the ceramic, and the copper flows into and fills the intervening gap. On the cooling cylcle, the flange contracts at a faster rate than the ceramic disc, so the disc is held in compression. Since ceramic is approximately nine times stronger in compression than in tension, this seal should be able to withstand thermal cycling. A seal of this type was heat cycled up to a temperature of 600°C without failure.

It became apparent later on that the solid design was not reliable at temperatures above 600°C. Therefore, the flexible window mounting system was incorporated into the final tube design, and, to insure the reliability of this component, the flexibility was increased and the construction details were simplified.

(2) Output Transition System

The requirements for the design of the QKA855 output system were identical to those for the QKA857 system except for the frequency range and the over-all length. Two types of output system were considered for the QKA855.

(a) Waveguide Output System #1

Waveguide output system #1, for the QKA855, consisted of a smooth taper of the ridges similar to the approach described for waveguide output system #1 in the QKA857 section of this report. The dimensions at the delay line end of the waveguide were determined by the impedance of the DR-19 waveguide for this frequency range, by the wavelength, and by the length and spacing between the interdigital fingers.

A prototype waveguide assembly of this design was fabricated and tested. An attenuative delay line was used as a load. The reflection coefficient vs frequency obtained in these tests is shown in Figure 22.

A prototype QKA855 window assembly using plastic as the dielectric material for experimental purposes was added to the waveguide output assembly to simulate the complete output system, and the resulting reflection coefficient vs frequency is plotted in Figure 23. The results depicted in Figures 22 and 23 were achieved by modifications of the waveguide dimensions. The design parameters were adjusted, and the results were reproducible.

Use of this output system requires a critical configuration and positioning of the anode. On M-type backward-wave oscillators, the anode acts as an isolator between the energy propagation of the delay line and the electron gun. Another important function of the anode is to provide termination of the delay line to direct the propagated wave from the delay line to the output rf system. Because of the proximity of the anode to the junction between the waveguide section and the delay line, the position configuration of the anode affects the match between the output waveguide section and the delay line. Figures 22 and 23 show that the maximum reflection coefficients occur at the low frequency end of the QKA855 tuning band. This is the area in which the effect of the anode is most critical.

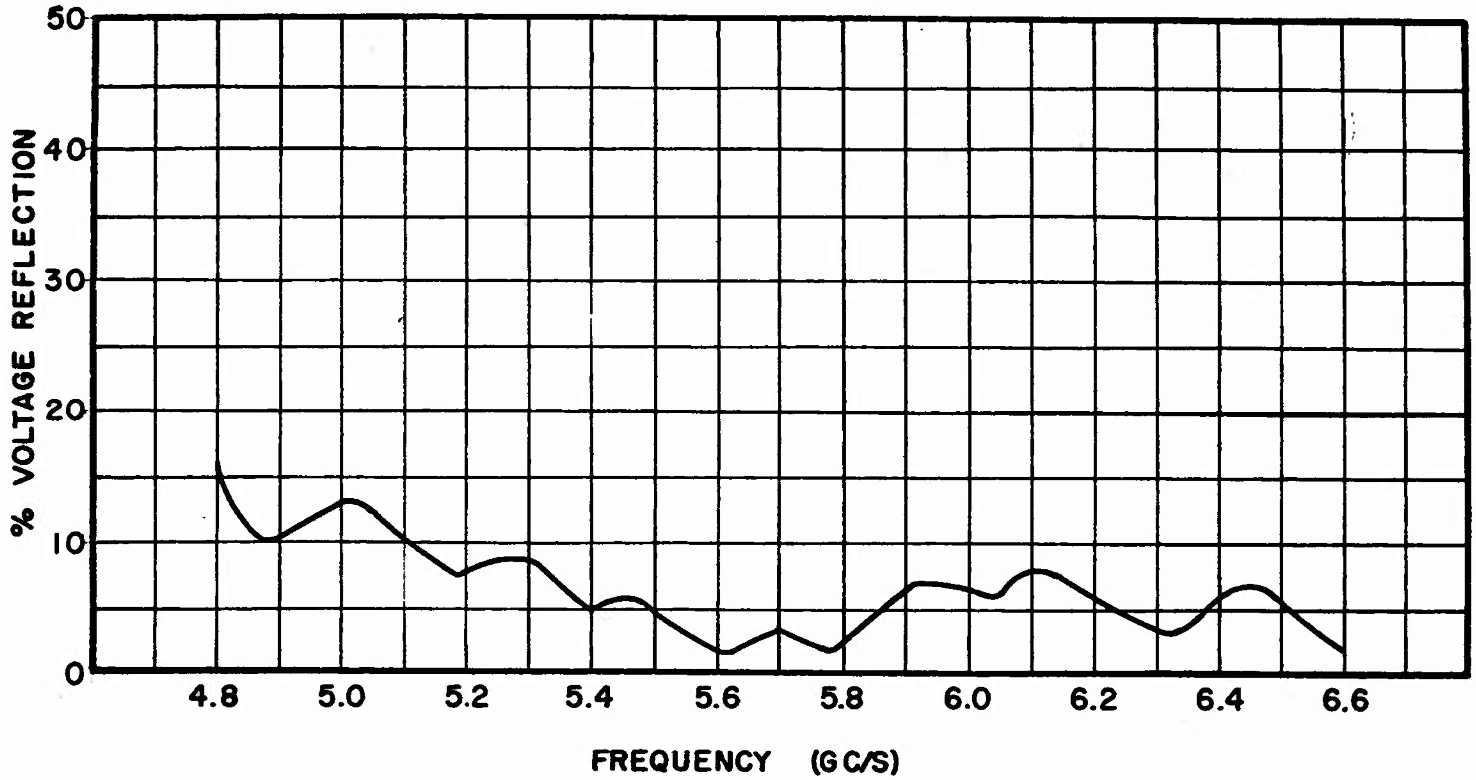


FIGURE 22

WAVEGUIDE OUTPUT

(IRON PLATED DELAY LINE AS A LOAD)

QKA 855

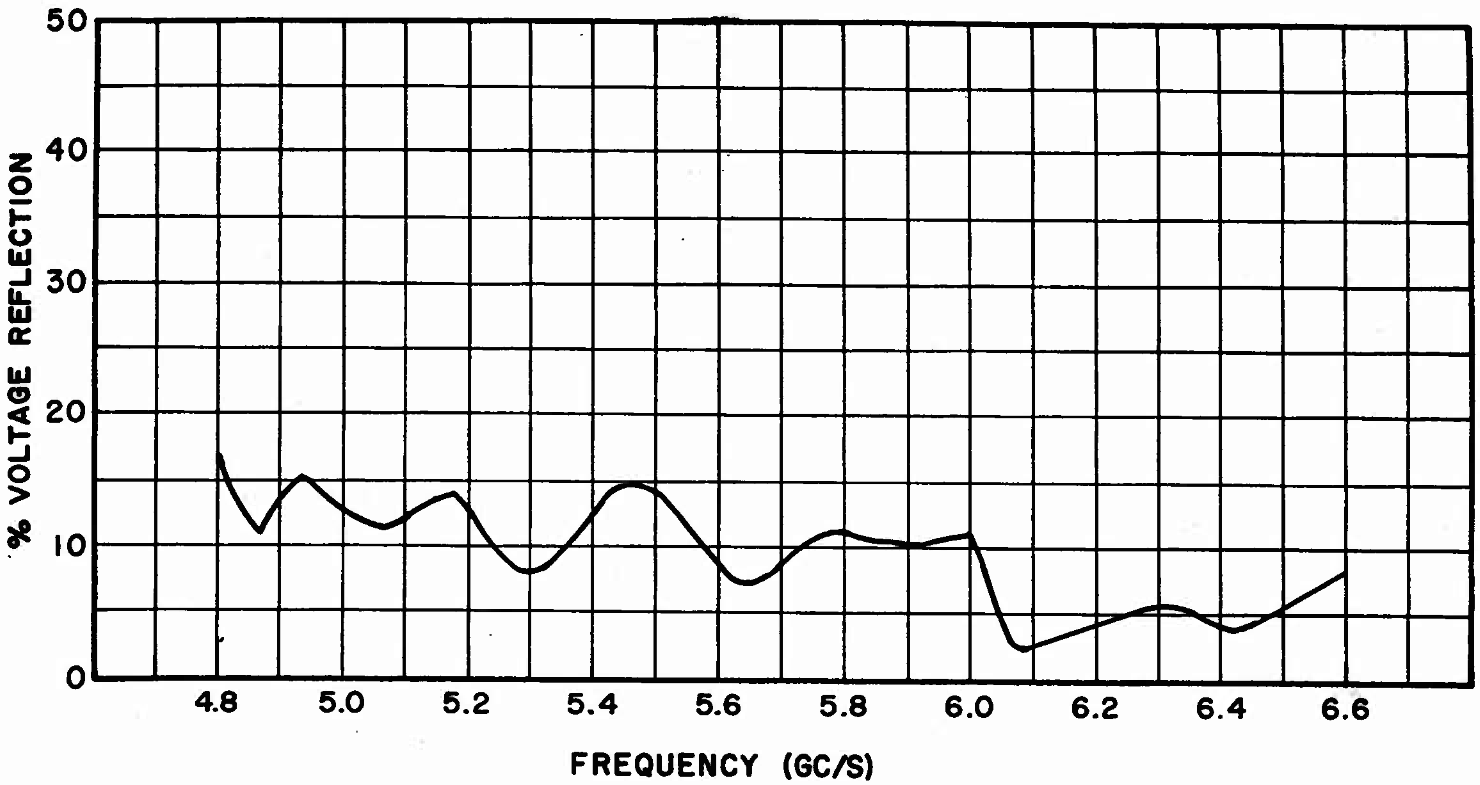


FIGURE 23

WAVEGUIDE OUTPUT AND WINDOW
(IRON PLATED DELAY LINE AS A LOAD)
QKA 855

(b) Waveguide Output System #2

Waveguide output system #2 consisted of a series of steps in the ridges and was similar to waveguide output system #2 described for QKA857. The lower frequency of the QKA855 gives more practical dimensions for the ridges than was the case in the QKA857. Of the two waveguide systems described, the system designated as #1 was chosen as the final design because of early success with this type of system and its ease of manufacture.

A plot of voltage reflection vs frequency for the prototype QKA855 tube featuring the final output system is shown in Figure 24. A maximum value of 30% occurs at the high frequency (6550 Mc) end of the band. This curve is typical of tubes constructed during the program.

Figure 25 is a photograph of the cylinder-output assemblies for both the QKA857 and QKA855 tubes.

c. Electron Gun and Optics

The electron gun for the QKA855 was based on the QKA634/773A design and is similar to that of the QKA857; wherever possible, component parts of the two electron gun assemblies were standardized to reduce costs. The essential differences include a longer cathode and a different heater assembly. Adjustments in the position of the elements were later incorporated to obtain optimum performance under sole tuning conditions, and modifications were introduced to dampen resonances occurring during vibration.

It proved advantageous at a later time to employ a reservoir type of thermally choked cathode structure, with nilvar supports on the reservoir cathode, to take advantage of this material's inherent heat-choking action. This heat choke facilitated the designing of a lower temperature heater. Previous data had indicated that the lower the temperature of the heater, the longer the life of this element. Diode emission tests showed that this type of cathode-heater assembly would withstand more than one thousand hours of life.

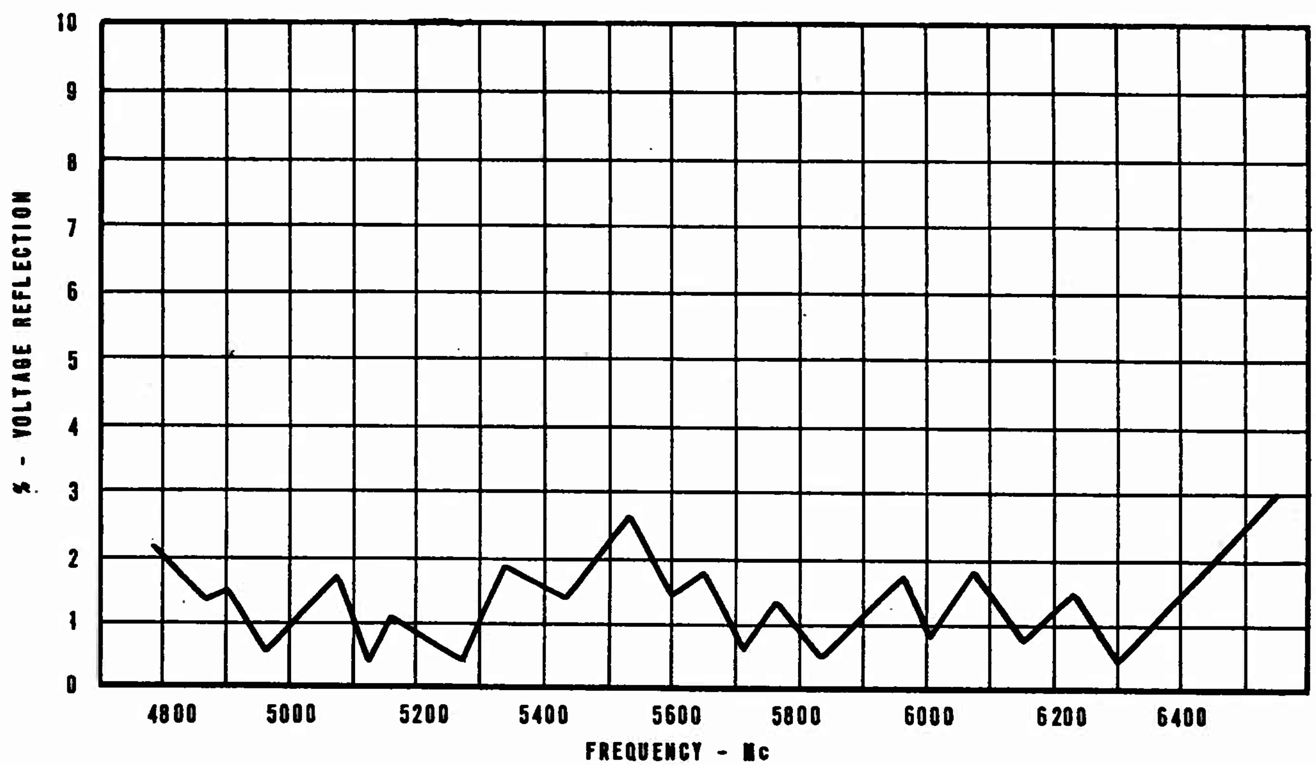


FIGURE 24 TYPICAL COLD TEST CURVE FOR THE QKA855

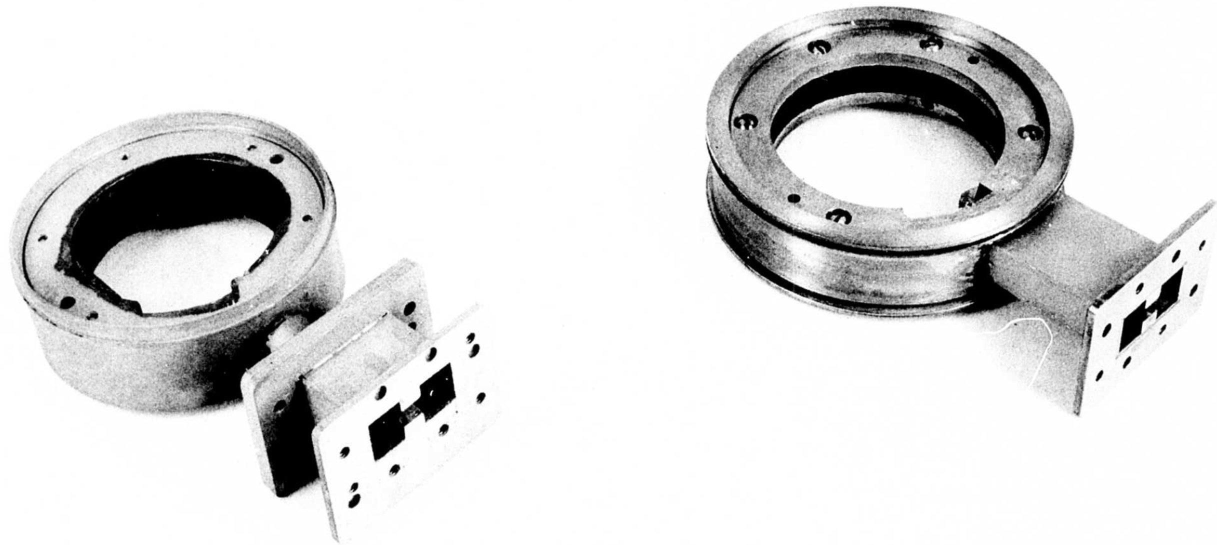


FIGURE 25 CYLINDER OUTPUT ASSEMBLIES FOR QKA857 AND QKA855

Figure 26 shows a typical QKA855 emission characteristic.

d. Magnets

The specified electron tube drawings for the QKA855 required a reduction of both the diameter and the height of the magnets.

Prototype magnets and the compensation contained within them are identical with those used on the QKA857 program, and all comments pertaining to the magnets and the compensating materials appear in the QKA857 sections.

Methods were developed for externally magnetizing the magnet to a level sufficient to allow adequate stabilization.

Figure 27 is a photograph of the packaged QKA855, showing the magnets used.

e. Electrical Results

Seven prototype tubes were constructed during the Phase I period. The initial tubes were plagued with low power points at the high frequency ends of half-band tuning tests, but voltages, currents and inter-element capacities were well within the requirements of the specifications. Improvements were observed after the sole-to-anode spacing was increased to provide a better launching position for the beam and after symmetrical tabs (cathode shields) at grid potential were placed over each end of the cathode to control beam leakage. Further improvements were provided by the introduction of a higher impedance delay line. Tube #6 featuring these modifications met all of the power requirements of the specification. In addition, this tube had no discontinuities in a 1.5/1 mismatch, and all recorded currents, voltages and inter-electrode capacities called for in the specification were within the prescribed limits. Figures 28, 29 and 30 show the tuning rate and power output vs frequency under sole and anode tuning conditions.

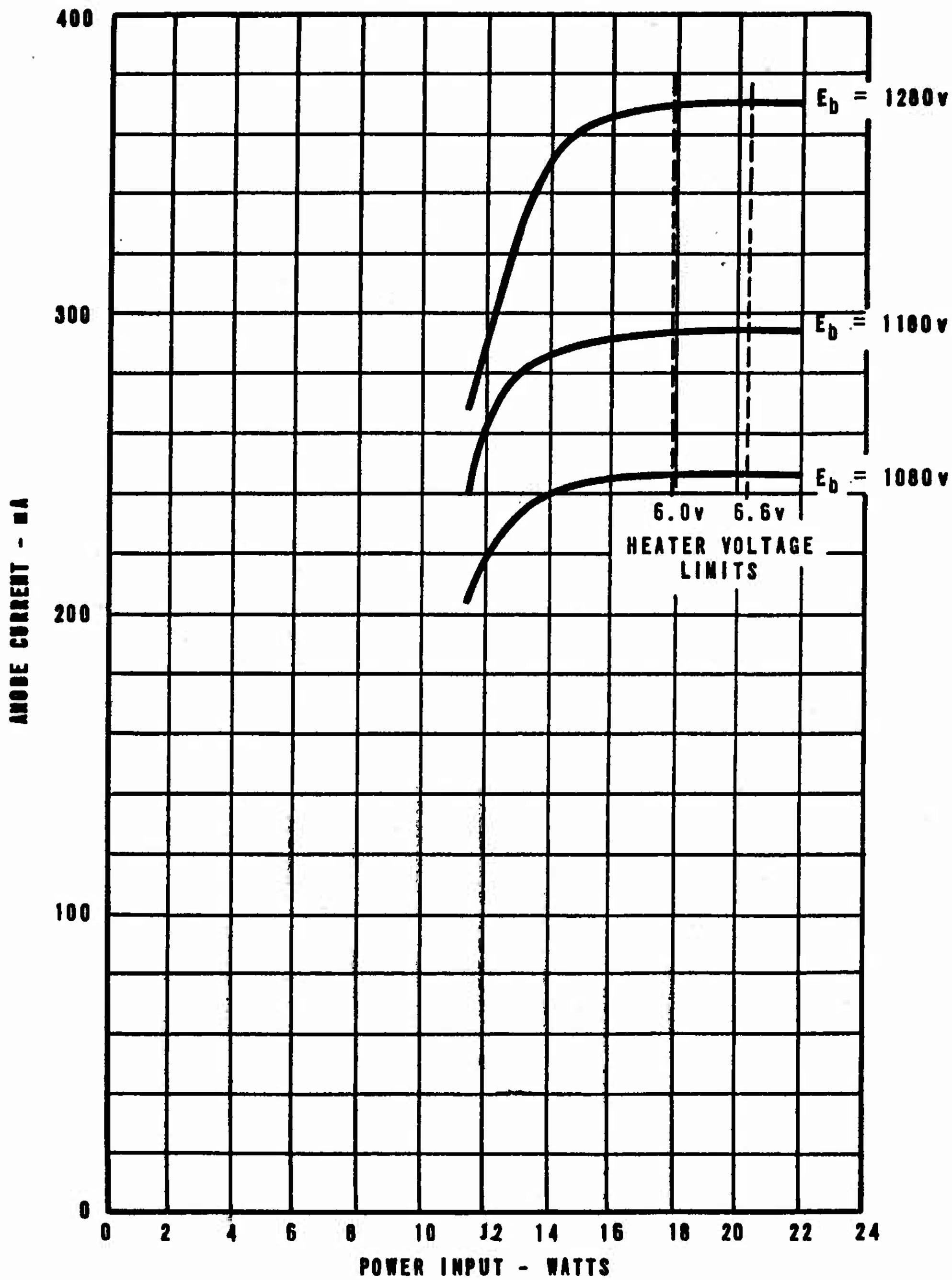


FIGURE 26 QKA855 EMISSION CHARACTERISTIC

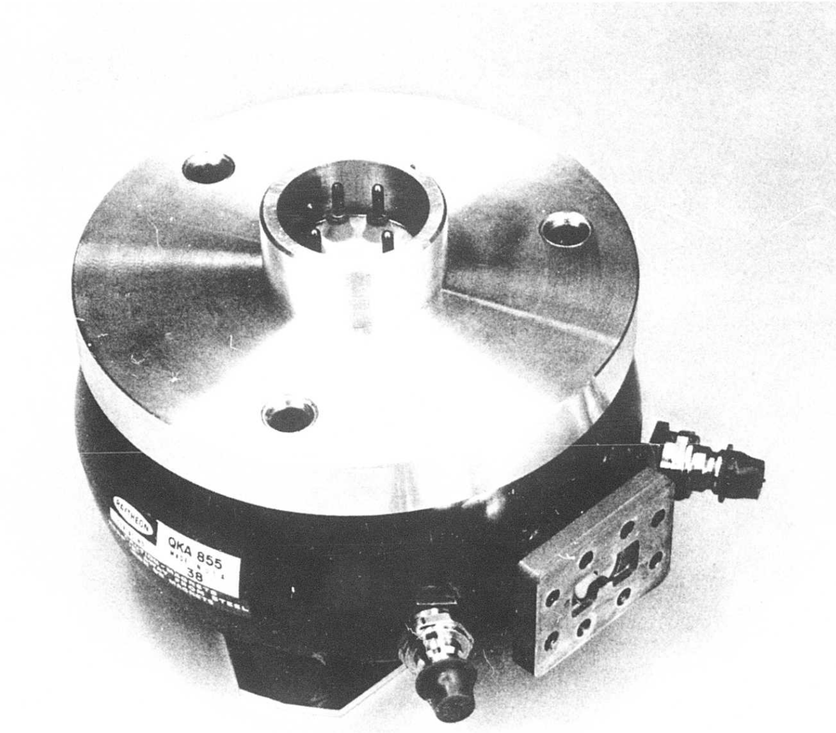


FIGURE 27 PACKAGED TUBE - QKA855

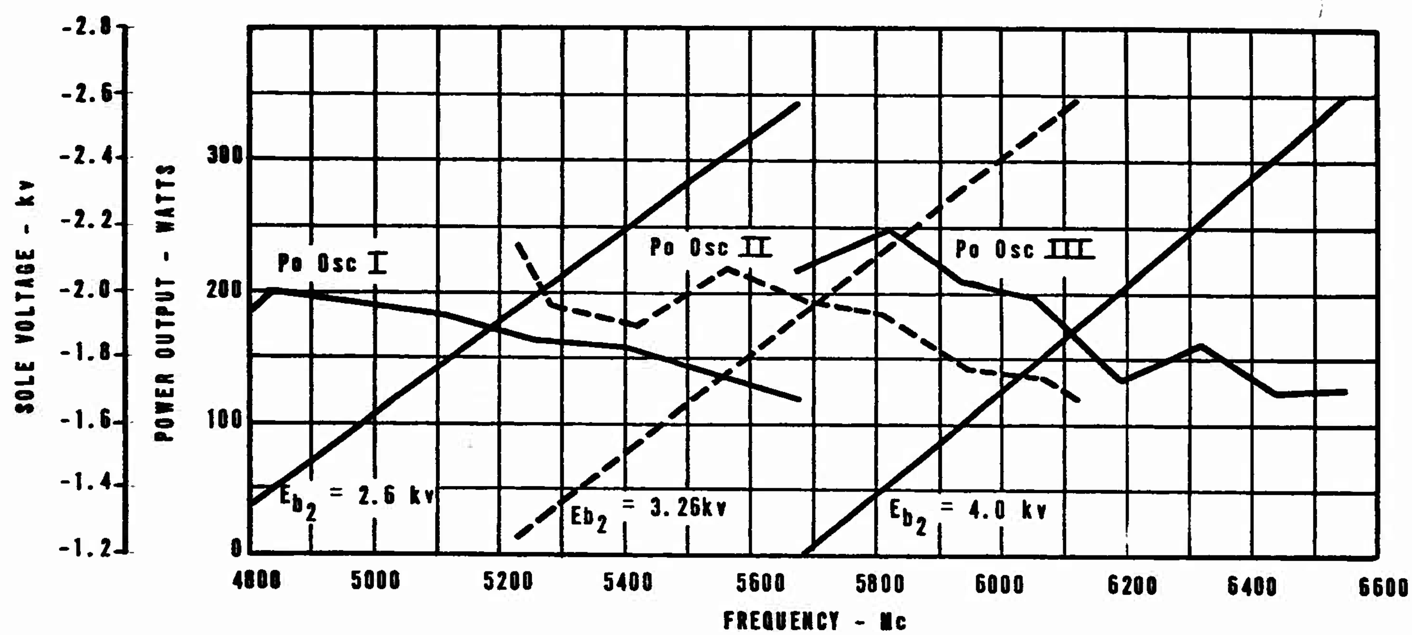


FIGURE 28

QKA855 SOLE TUNING CHARACTERISTICS

I_{b_2} = 220 mA

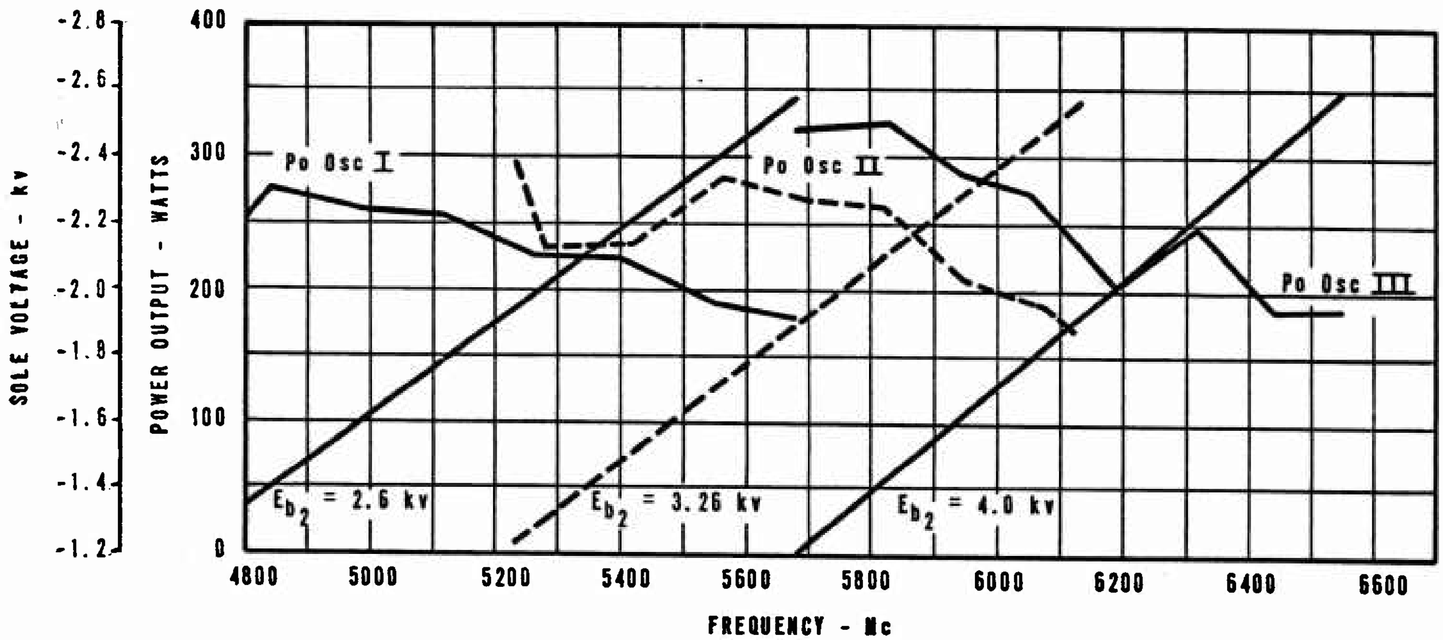


FIGURE 29 QKA855 SOLE TUNING CHARACTERISTICS

$I_{b_2} = 300$ mA

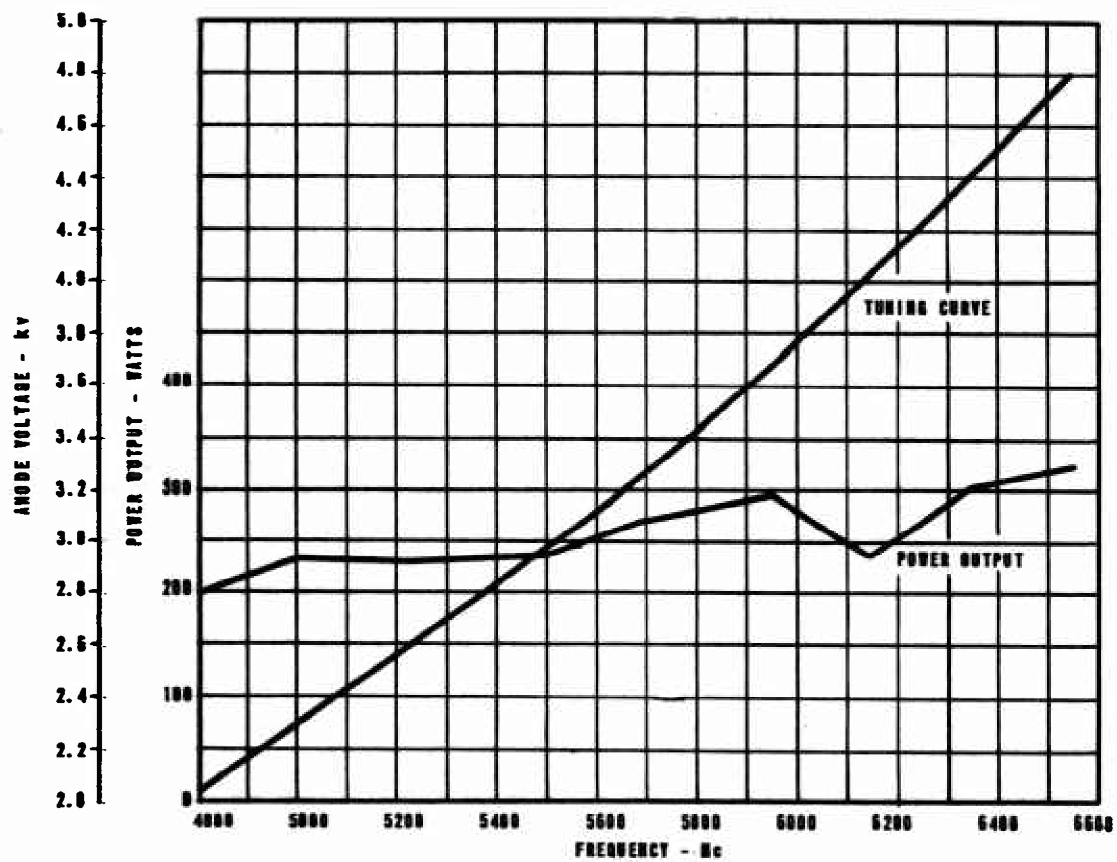


FIGURE 30 QKA855 ANODE TUNING CHARACTERISTICS

I_b = 300 mA

f. Additional Refinement

Upon the completion of this portion of the program, wherein the tube met all of the objective specifications, customer usage required that the tubes mate to their particular DR-19 "O" ring flange seal.

This unspecified requirement meant an output redesign which terminated with a DR-19 flange. The redesign to a DR-19 flange termination was satisfactorily accomplished without exceeding the project's budgeted funds.

The three final QK855 tubes to be delivered on this contract will have the redesigned output which meets all the contract as well as customer requirements.

4. QKA857 (Band 8; 8500 - 11,000 Mc)

a. Delay Line

The delay line of the QKA857 was similar to the delay line used in the QKA634/773A tube. The QK634 line had already shown satisfactory anode tuning characteristics with respect to power output, spurious output, frequency discontinuities and heat dissipation.

During the early part of the program, QKA773A cylinder anode delay-line assemblies were subjected to vibration tests in accordance with the requirements of this specification. No mechanical resonances were detected.

The need for improved delay-line fabrication had been indicated by previous experience with the QKA773 and QKA634A tubes. Since the inter-digital line was formed by intermeshing the fingers of two mirror-image crowns, it was necessary to minimize the angular tolerance buildup for both crowns. If two crowns bearing the same angular deviations are used to form a delay line, then the errors become additive, and non-uniform spacing between finger results. This condition causes difficulty in achieving a properly matched line.

Crowns are made by cold forming copper slugs; therefore, parts tolerance is a direct function of hob dimensions. The delay line hob procured for the QKA857 program had a maximum cumulative angular error between finger slots of .0002 inch. Stringent controls were imposed on machining operations from the blanked slug to the finished crown, and these controls resulted in the fabrication of crowns with a total delay-line error not exceeding .001 inch. Errors as high as .003 inch had been experienced in previous X-band crowns, and the reduction of delay-line error by 200% demonstrated a significant improvement in delay-line match and a corresponding improvement in the output signal quality.

The crowns are shown in Figure 31.

FIGURE 31 DELAY LINE CROWNS - QKA857

b. Electron Gun and Optics

The basic electron gun construction used in the QKA634A/773A tube type was selected as the final design for the QKA857.

A 6.3-volt heater design was developed, and a modification of the QKA773 cathode design was also accomplished. This modification to increase the cathode barium reservoir insures a larger supply of emitting material, which should increase effective tube life. The new 6.3-volt heater was operated continuously in test vehicles for over 2000 hours without any significant changes in heater resistance. One prototype assembly was repeatedly cycled in the operating magnetic field of the QKA857. One cycle consists of applying 1.8 volts to the heater, waiting 30 seconds, then applying 6.3 volts, waiting 30 seconds then turning off the voltage for 5 minutes to complete the cycle. After 2000 cycles, there was no significant change in the heater resistance.

Although the gun assembly used on the QKA634A/773A tubes passed the vibration tests required by the specification up to 500 cps, resonances were detected in the cathode support assembly and in the accelerator support assembly at frequencies of 1000 and 1500 cps. Changes in the cathode support were made, and the method of mounting the cathode support assembly to the cathode support legs was revised. These modifications moved the resonances of this assembly up to 1800 cps, well above the 1500 cps maximum requirement. At the same time, the accelerator support legs were changed to move the resonant frequency of the accelerator support assembly to 1800 cps. An electron gun featuring these changes was constructed and was subjected to the full vibrational requirement of the specification (5 G amplitude, 50 to 1500 cps, 3 mutually perpendicular planes, 12 hours duration). No resonances or dimensional changes were detected. The gun assembly was mounted on the sole to simulate the conditions of the final tube design for the above vibration evaluation.

Later in Phase I, it was necessary to add shielding to improve tube performance. In addition, tabs were attached to the cathode support to dampen heater ceramic resonances during vibration.

c. Output System

A significant portion of the QKA857 development time was devoted to the design and manufacture of an rf output structure compatible with the following terms of the specification:

(1) Compatibility with DR-19 waveguide.
(2) Ability to withstand 5-1500 cps vibration at 5 g and 15 g shock impulse.
(3) Not to extend more than 3.750 inches from axial center line of tube and to be centered 2.000 inches below the mounting plate.

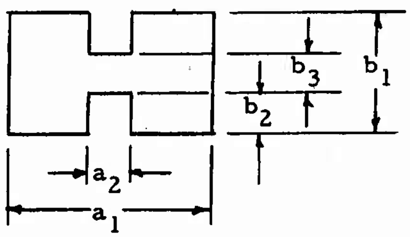
In addition to the above requirements, the output system must present a low VSWR over a broad range of frequencies. It must be able to transmit continuous power of the order of .4 KW. Fabrication techniques must maintain high tolerances at low cost.

Three output system designs were considered during this period.

(1) Waveguide Output System #1

Waveguide output system #1 consisted of a smooth taper of both ridges and waveguide walls of the DR-19 waveguide into the anode cylinder and output termination of the delay line.

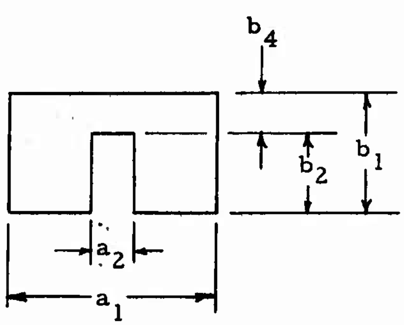
The schematic sketch below represents the inside dimensions of the DR-19 waveguide



a_1 = 1. 025 inch nominal
a_2 = . 256 inch nominal
b_1 = . 475 inch nominal
b_2 = . 142 inch nominal
b_3 = . 191 inch nominal

The average impedance of DR-19 waveguide over the QK857 frequency range, as taken from Technicraft data, is approximately 217 ohms. To fasten this waveguide mechanically to the anode cylinder and to achieve a proper impedance match of the waveguide to the delay line, the dimensions of the DR-19 waveguide must be transformed to a single ridge system. This is accomplished by linearly tapering the dimensions of the DR-19 double ridge waveguide to a single ridge waveguide over a length of approximately 2. 5 inches.

The dimensions at the tube end are as follows:



a_1 = . 500 inch nominal
a_2 = . 080 inch nominal
b_1 = . 231 inch nominal
b_2 = . 211 inch nominal
b_4 = . 020 inch nominal

The impedance of a simple ridge guide varies directly as b_4. At the tube end, an impedance of 59 ohms can be calculated for the single ridge waveguide. A parallel plate impedance approximation of the QKA857 delay line yields a value of 83 ohms. The waveguide was so designed that the b_4 dimension could be easily modified for impedance matching of the guide to the delay line.

A waveguide assembly was constructed and evaluated. This assembly was fastened to a special cylinder crown assembly in which the interdigital fingers were completely attenuated so as to function as a matched load. The maximum reflection coefficient was 15% in the QKA857 operating band. A great deal of time was spent matching this system by adjusting both waveguide and tube geometries. The dimensions of the waveguide sections were critical, and additional work was required to make this output system more reliable and simpler to fabricate.

When this assembly was subjected to the full vibrational requirements of the specification, no detrimental effects were observed.

(2) Waveguide Output System #2

Waveguide Output System #2 involved a series of steps in the ridges of the DR-19 waveguide to achieve an impedance transformation from the output termination to the delay line. During this report period, this type of waveguide output system was designed with the step dimensions being taken from the "Tables for Cascaded Homogeneous Quarter-Wave Transformers" by L. Young,* and from existing impedance relations for ridge waveguide. The dimensions for the steps obtained by the above method over the allowable length of 2.465 inches closely approximated a smooth linear taper of the ridges; hence, this approach was discontinued in favor of the next approach.

(3) Variable Impedance Coaxial Step Transformer

The coaxial output system uses a coaxial step transformer in which one end of the center conductor is attached to the output finger of the delay line. The other end of the center conductor is attached to one of the ridges of the DR-19 waveguide. Since the junction discontinuity of the coaxial line to the output finger was minimized on the QKA634 and 773 programs, the major problem was to match the coaxial line to the DR-19 waveguide.

* Young, Leo, "Tables for Cascaded Homogeneous Quarter-Wave Transformers," IRE Trans, on Microwave Theory and Techniques, April, 1959, pp. 233-237.

An assembly of this type was constructed and tested obtaining maximum reflection peaks of 5% across the band. An rf window, as described later in this report, was then added to the assembly, and the resulting frequency vs reflection coefficient is shown in Figure 32. The maximum and average values of reflection coefficient compare well with values for the present QKA634/773A output systems. Considerable work was required to achieve the above match; but once the exact design parameters had been established, the output system described above was reproducible.

The choice to use this system was prompted by the reproducibility of its electrical and mechanical characteristics.

This assembly, which was built with a center conductor of solid cross section, was subjected to vibration tests over the 55-1500 cps spectrum at 5 g's. During vibration, the center conductor-output finger assembly was inspected with stroboscopic "slip-sync" light. Low amplitude resonances were discovered at 100 and 1100 cps. These resonances were not severe enough to cause the output finger (which is connected to the center conductor) to short circuit to the adjacent finger of the delay line.

A severe vibration in the region between 1290 and 1330 cps nearly caused short circuiting of the output finger to the first finger of the delay line at the maximum amplitude. To raise this upper limit of resonance above 1500 cps, the solid center conductor was replaced by one of tubular cross section. The tubular center conductor showed no resonances at 5 g in the 55-1500 cps range.

d. Output Window

In the design of a ceramic window for the QKA857, a low-porosity alumina disc with a dielectric constant of approximately 9 was chosen because of its inherently satisfactory vibration, shock and thermal properties. Discs of this design can be manufactured easily at low cost.

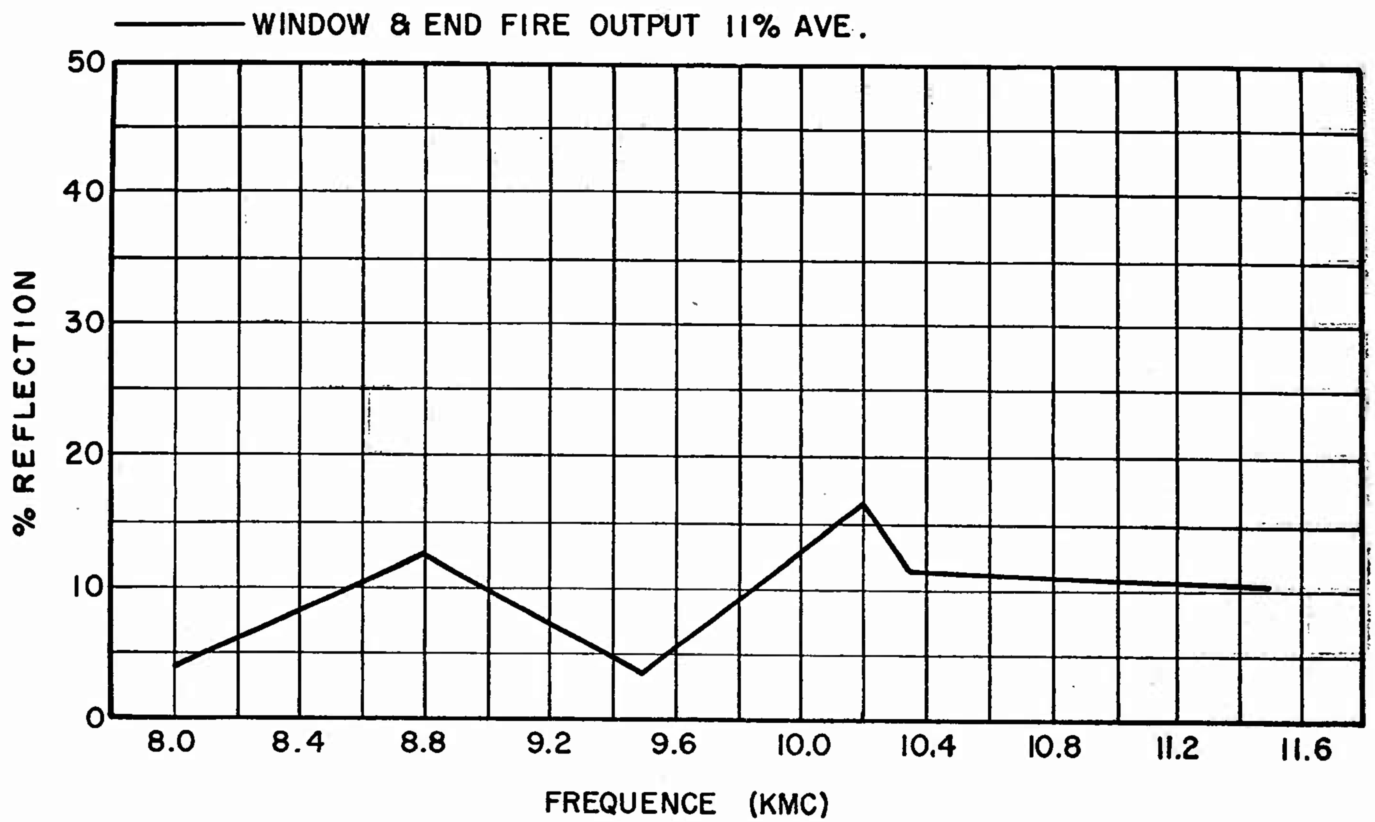


FIGURE 32

QK857 OUTPUT ASSEMBLY MATCHED TO 50 Ω DUMMY LOAD

To maintain the vacuum seal, the outer periphery of the ceramic disc is metalized. It is then fired and brazed to a retaining ring, which, in turn, will be brazed into the output flange of the tube.

An outstanding feature of this design is that the over-all thickness of the window assembly is less than .250 inch. This allows, within the specifications of the electron tube drawing, a maximum transition length from the DR-19 waveguide to the delay line, which will facilitate solution of the impedance matching problem.

A window assembly of this type was constructed. Measurements were taken of the percentage reflection coefficient (the percentage reflection coefficient is equal to the reflected voltage division by the incident voltage times 100) vs frequency for this window inserted into DR-19 transmission line. The maximum reflection coefficient in the operating band, 8500-11,000 Mc, was 6%.

The window assembly was heat cycled to 500°C without failure. After the fourth cycle at 500°C, the window developed a vacuum leak in the ceramic seal. The seal area was redesigned to enhance flexibility and was subjected to the specified vibration test. It was found to be leak-tight and electrically satisfactory at the conclusion of the test. The same assembly was also subjected to the full shock test requirement without detrimental effect.

The complete output system. shown in Figure 33, exclusive of the delay line, has an intrinsic VSWR of approximately 1.22 (10% reflection coefficient) when coupled to DR-19 waveguide. This value is valid from 8500 to 11,200 Mc and is not adversely effected by environmental conditions. The system, when coupled to the active delay line, shows maximum VSWR of less than 1.855 (30% reflection coefficient). A VSWR less than 1.855 means that nowhere will line power loss exceed 9%. It is desirable to maintain an average VSWR of less than 1.5 (20% reflection). Cold test data have proven the QKA857 propagation structure to be below this value. Figure 34 is a plot of percent voltage reflection vs frequency for a typical Band 8 tube.

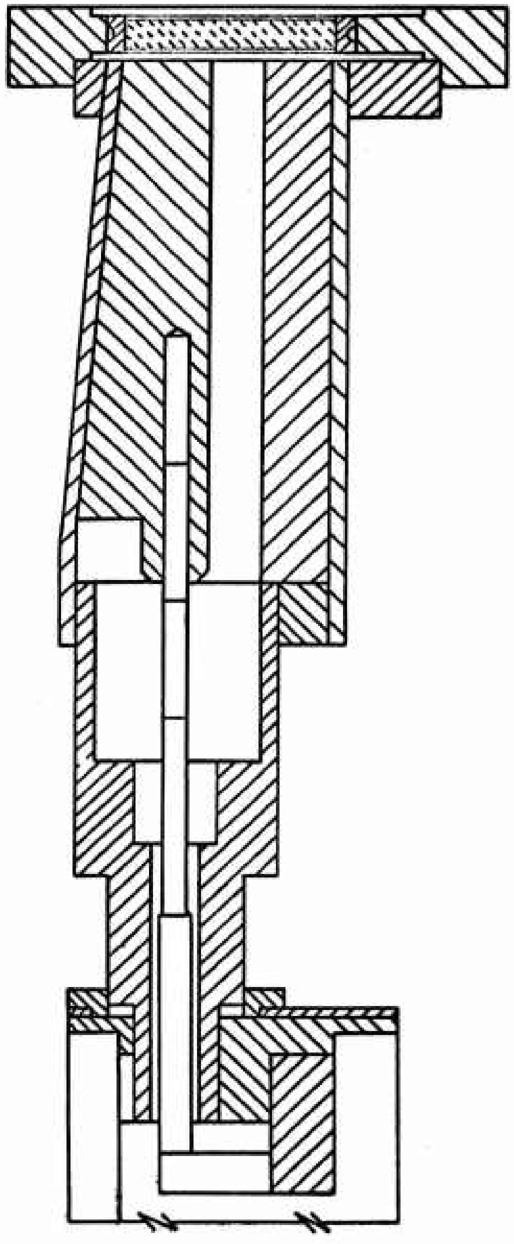


FIGURE 33 QKA 857 OUTPUT

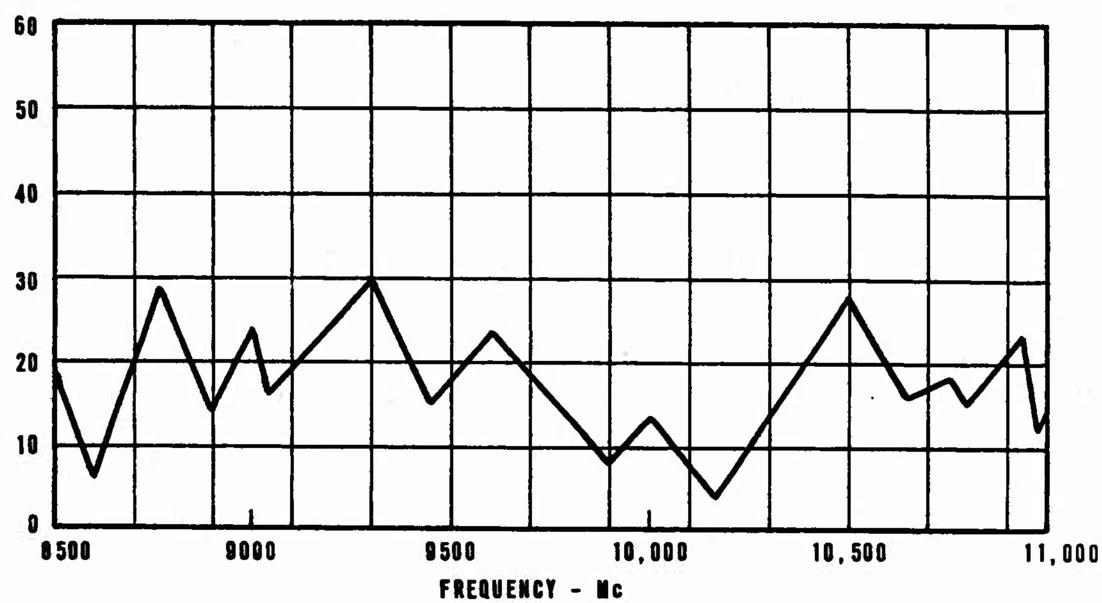


FIGURE 34 COLD TEST QKA857 #3

22% AVE. REFLECTION
30% MAX. REFLECTION

A packaged tube was vibrated in three mutually perpendicular planes from 5 - 1500 cps at the specified "g" level. No adverse effects to its electrical operation were observed.

e. Magnets

The specified electron tube drawing for the QKA857 requires a reduction of both diameter and height of the magnets used on the QKA713A. To use a magnet of this reduced size, it was necessary to redesign the QKA857 magnet gap by lowering the exhaust and sole support covers and by decreasing the thickness of the crown flange. Effort during this program was directed towards the achievement of saturated magnetization of the QKA857 magnets from external magnetizing techniques. Success was ultimately had with a combination of a pulsed magnetizing coil and a continuous field magnetizer.

Magnets were successfully compensated and proven out in the operational tubes. Figure 35 is a photograph of a magnet with its representative pole pieces and Figure 36 is a photograph of the packaged QKA857.

f. Electrical Results

During Phase I, ten prototype tubes were constructed, six of which were built for the evaluation of modified optics and delay line parameters. These ten tubes showed consistent improvements in power output and starting current levels. Low power was evidenced initially at 220 mA and 275 mA operation, and this was linked to the proximity of the covers to the interaction space lowering beam coupling and interaction efficiency. In addition, the sole-to-anode concentricity had been exceeding the design limitations. An effort was made to reduce sole-to-anode eccentricity below . 001 inch; and sole end shields were extended over the interaction space, and the space between these shields and the interdigital line was reduced to . 013 inch.

FIGURE 35 QKA857 MAGNET WITH ITS REPRESENTATIVE
POLE PIECES

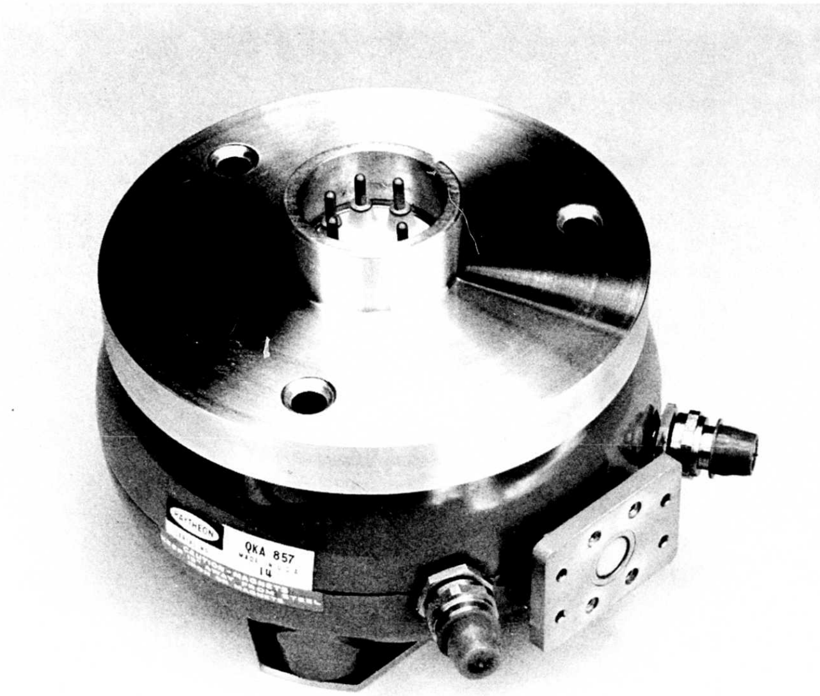


FIGURE 36 PACKAGED TUBE - QKA857

QKA857 #3,constructed towards the end of Phase I with all of the above improvements,complied with 90% of the requirements. Spurious signals had been minimized below 20 db, and no frequency discontinuities had been observed during operation into a 1. 5/1 mismatch. Figures 37 through 39 are the power vs frequency curves for this tube. Figures 37 and 38 show half-band sole tuning characteristics. The slanted lines depict sole voltage sweep versus frequency for each of the oscillations. The remaining curves represent power vs frequency. The data for Figure 37 were taken at 220 mA anode current, while the data in Figure 38 were taken at 275 mA anode current. Figure 39 represents the anode tuning characteristics. It can be seen from these curves that the tube passed all power and voltage requirements, Oscillations I through III.

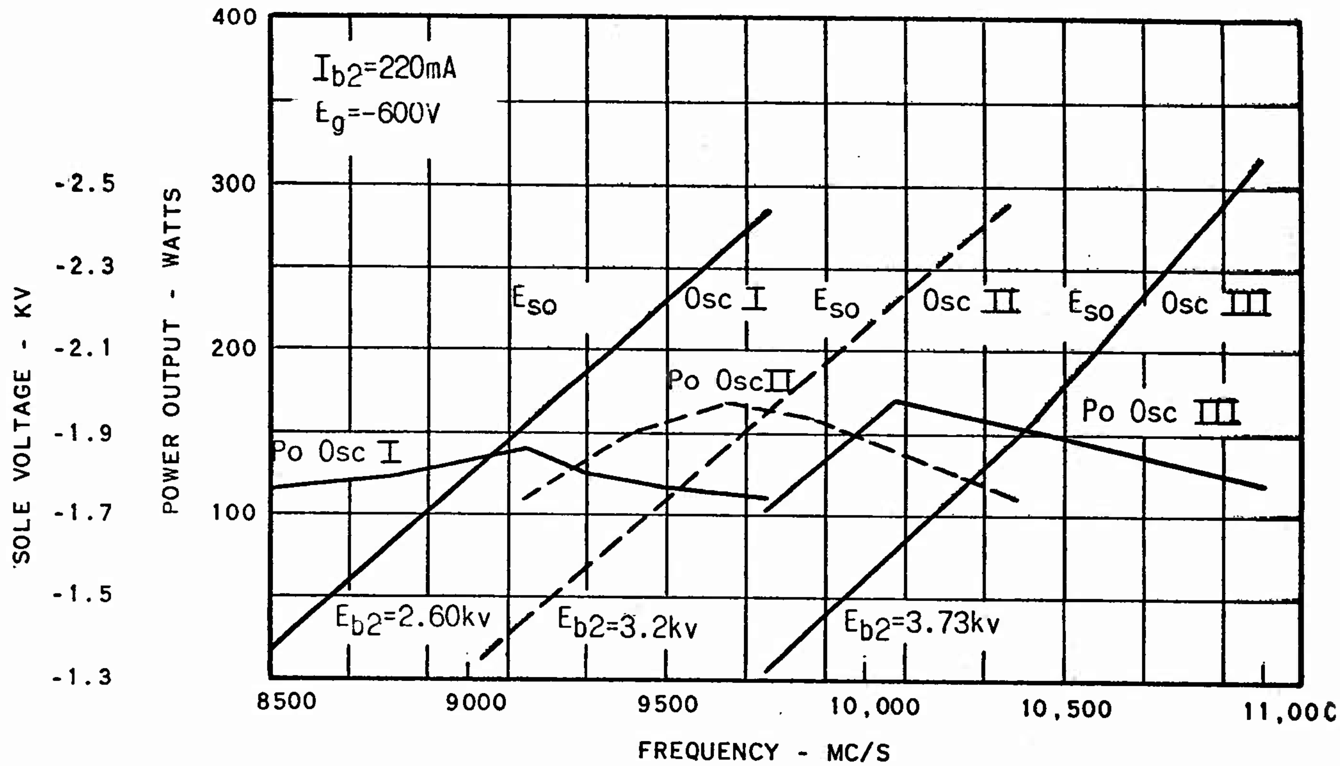


FIGURE 37 QKA857 #3 ELECTROMAGNET - 1/2 BAND SOLE TUNE

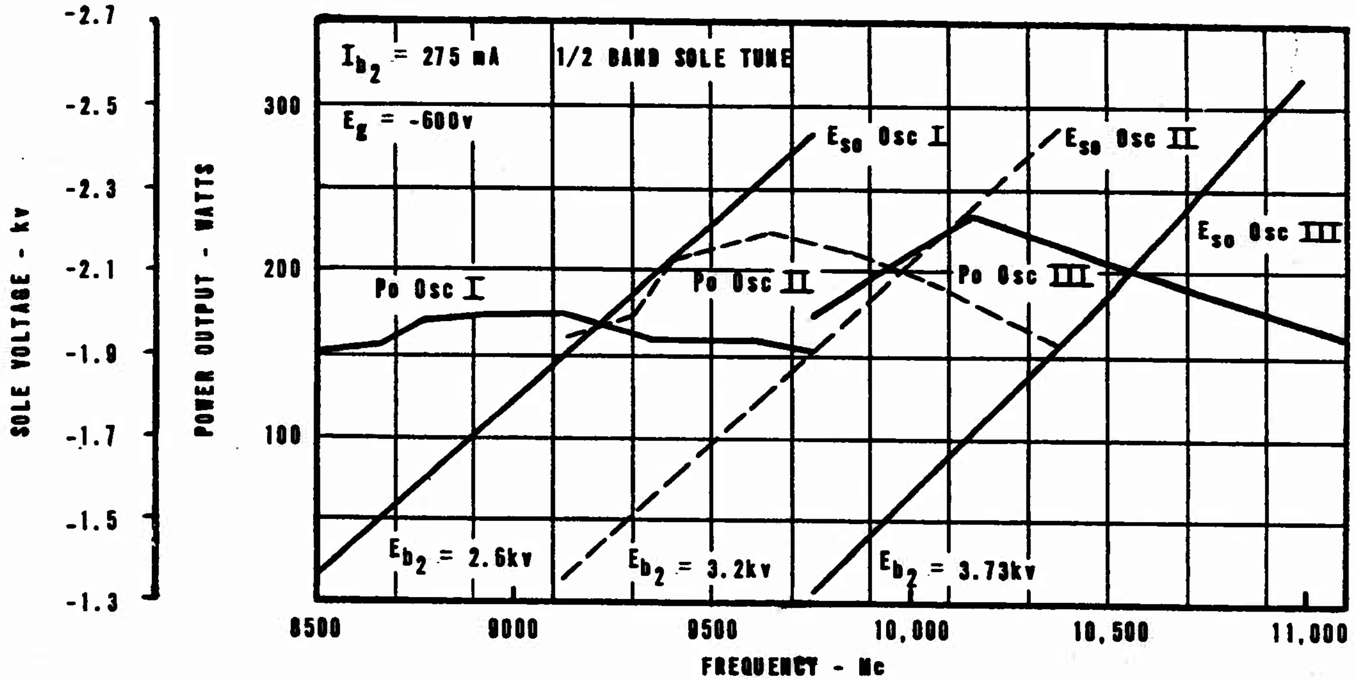


FIGURE 38 QKA857 #3 PERFORMANCE CHARACTERISTICS SOLE TUNING

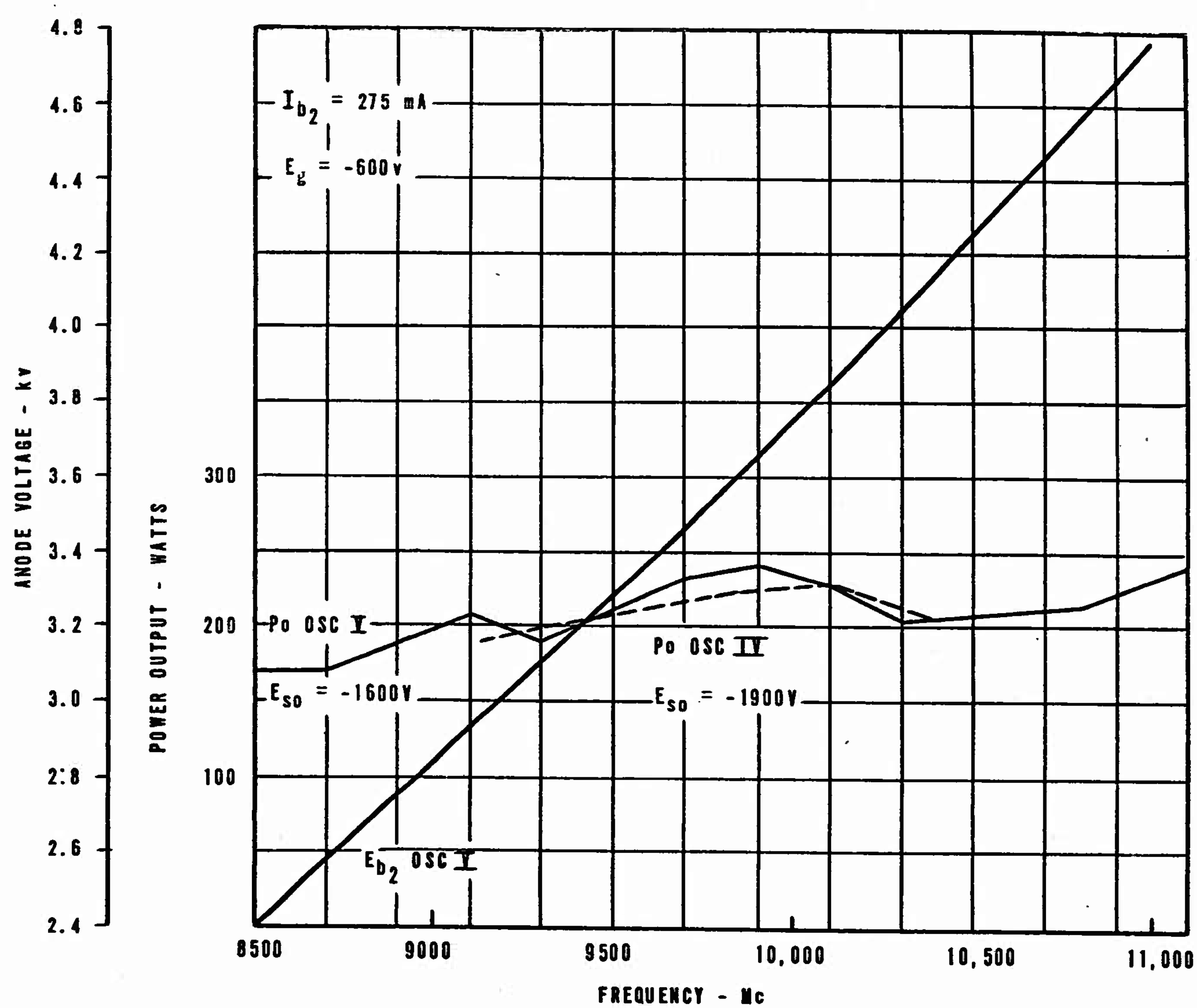


FIGURE 39 QKA857 #3 ANODE TUNING CHARACTERISTICS

Phase II: PRODUCTION-FABRICATION AND EVALUATION

1. Phase Objectives

During the Phase I program, tubes of each type had been produced to meet all of the specified electrical requirements; and the mechanical, processing and electrical specifications had been brought to within ten percent of the final versions. Work on Phase II was initiated on 1 April 1962 and continued for nine months through December 1962.

Phase II was devoted to

a. Production-fabrication of sample lots of QKA851, QKA852, QKA855 and QKA857 tubes in accordance with the approved final specification.

b. Environmental and life testing of several tubes of each type and their subsequent evaluation.

c. Investigation of the causes of failure (in some instances).

d. Completion of the mechanical, processing and electrical specifications.

By using the final data obtained in the Phase I effort, sufficient Band 2, 3, 5, and 8 tubes were production-fabricated (to the extent practicable) to prove that both optimum and economical tube design and manufacturing methods and processes had been achieved, consistent with the objective criteria.

2. QKA851

a. Electrical Results

During the Phase II program, initial effort was directed towards the construction of tubes, based principally on the designs of the final prototype tubes produced towards the end of the Phase I work. Tubes were tested to meet the requirements of the ASRCTE Exhibit No. 7 Specifications 652a/615a, dated 1 March 1962, and five tubes passing all electrical tests were constructed during this period. Figures 40 through 42 show the power characteristics for QKA851 #010, typical of the tubes built during Phase II. Figure 40 represents the anode tuning curve at 300 mA, in which power output is plotted vs frequency. Figure 41 shows the 300 mA half band sole tuning performance in which power output is plotted against frequency. Figure 42 represents the 220 mA half band sole tuning data in which power output is plotted against frequency. In addition, no frequency discontinuities into a 1.5/1 mismatch or spurious signals in excess of the 15 db minimum limitations were observed under the standard operating conditions in any oscillation.

Figure 43 is a graph of the cold test results from QKA851 #007 in which voltage reflection is plotted against frequency. From this curve, it can be seen that the maximum reflection peak obtained was 15%. These data are representative values from models constructed during Phase II.

Three tubes meeting the electrical requirements were placed to one side and will be delivered to the Air Force when notice of acceptance and approval has been received. The performance data of these tubes are given in Tables 1, 2 and 3 of the electrical data section, pages 128, 129 and 130. The remaining good tubes were subjected to life and environmental tests in accordance with the required specifications.

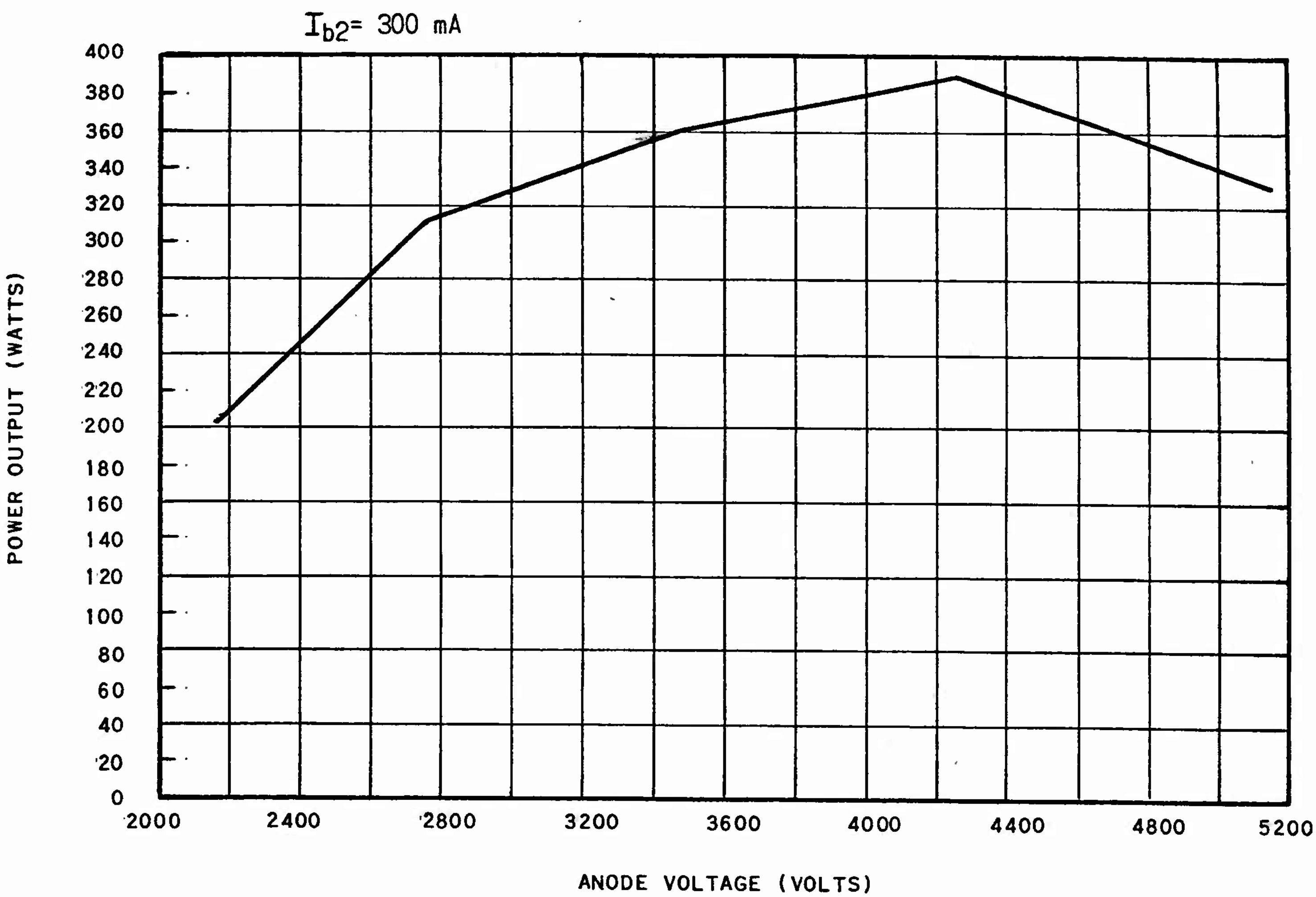


FIGURE 40 QKA851 NO. 10 POWER OUTPUT vs ANODE VOLTAGE

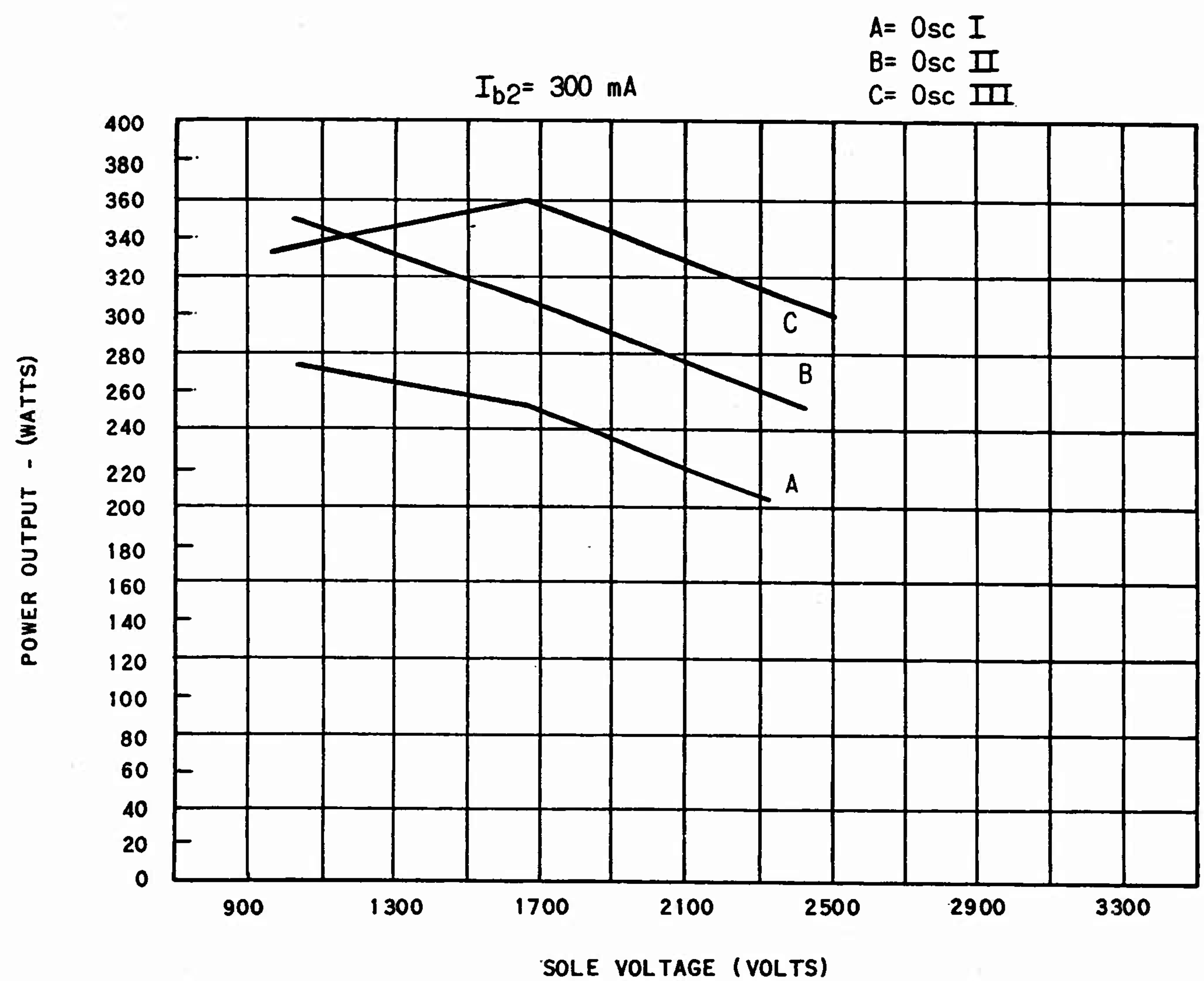


FIGURE 41 QKA851 NO. 10 POWER OUTPUT vs SOLE VOLTAGE

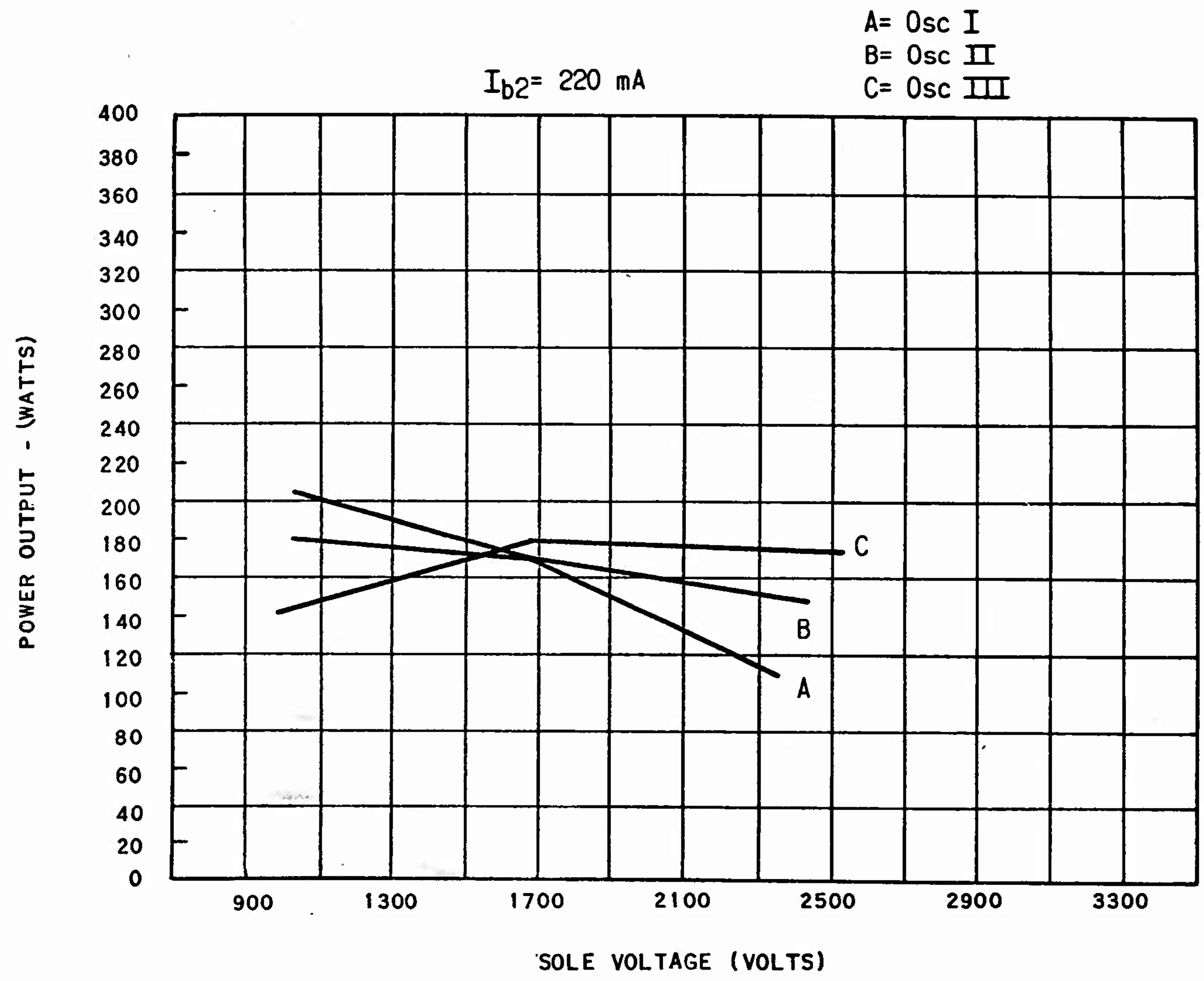


FIGURE 42 QKA851 NO. 10 POWER OUTPUT vs SOLE VOLTAGE

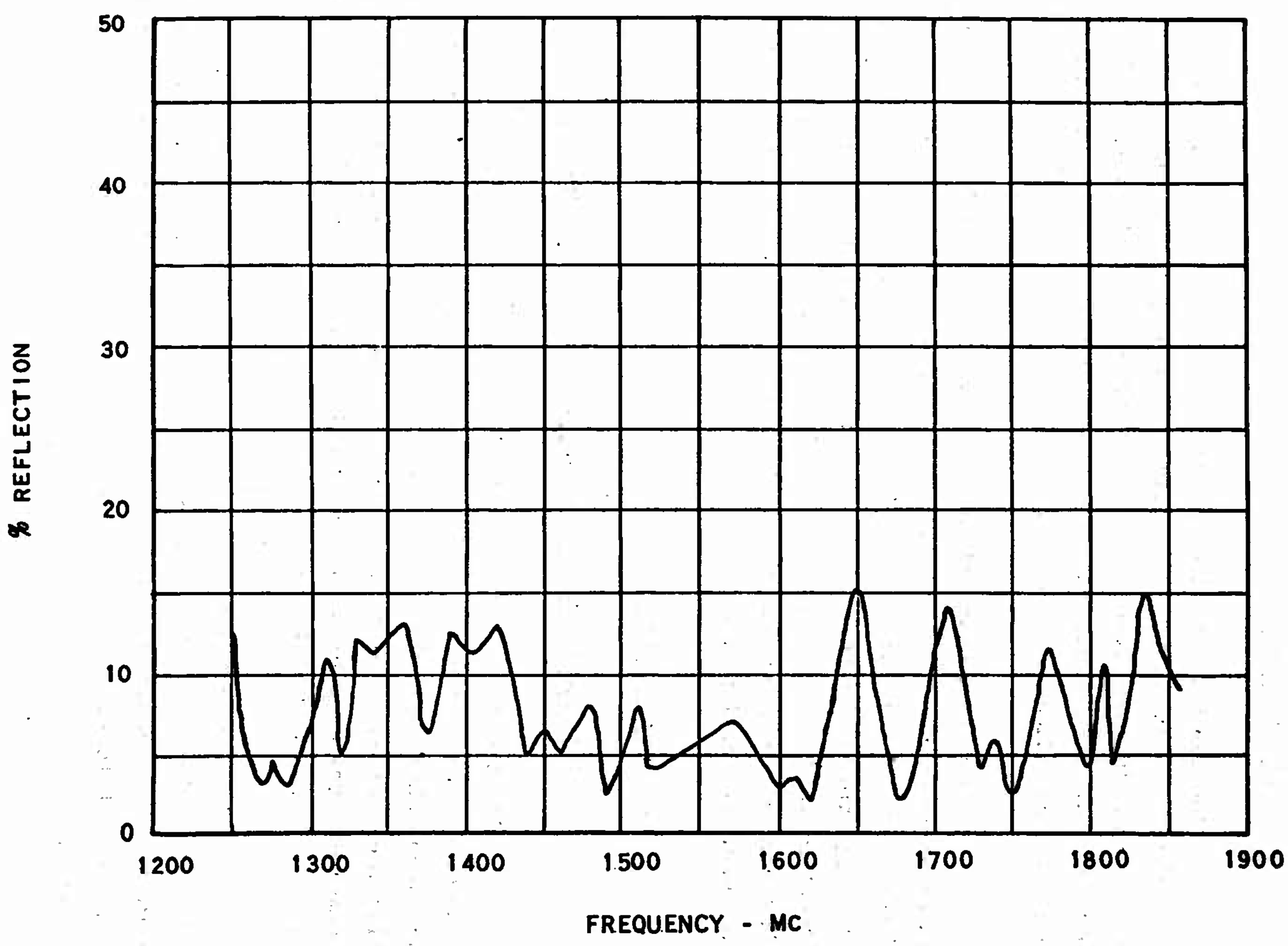


FIGURE 43 QKA851 NO.7 REFLECTION vs FREQUENCY

b. Shock Tests

The subject specifications require that the QKA851 tube be accelerated at 15 G for a duration of 11 $\pm$ 1 milliseconds in three mutually perpendicular planes (specified by reference to the electron tube drawing) with five shocks per direction in each plane. After this shock test, the tube is to meet the requirements of Oscillations I through IV.

Three tubes were subjected to this shock requirement; and electrical tests were conducted on each tube after the shock procedure had been completed. The 325 mA sole tuning data after shock test for the three tubes are shown plotted in Figure 44. The results are identical to those obtained before shock tests. In each case, no indications were observed of any substantial difference in power or other electrical characteristics. The QKA851 tube can meet the shock test requirements.

c. Thermal Tests

(1) Thermal Frequency Transit Time Tests

The thermal frequency transit time requirements state that the time allowed for the tube to reach a stabilized frequency after full beam current has been established shall not exceed two minutes. The tube is stabilized when the frequency difference between the maximum and minimum frequency measured over a period of one hour at intervals of five minutes shall not exceed .05% of fe (.05% x 1850 Mc = .925 Mc).

Three tubes were given the thermal frequency transit time test. The first tube drifted .34 Mc, the second tube drifted .79 Mc and the third drifted .32 Mc under the specified conditions; since the maximum allowed is .925 Mc, all three tubes passed the specified requirements in the tests conducted.

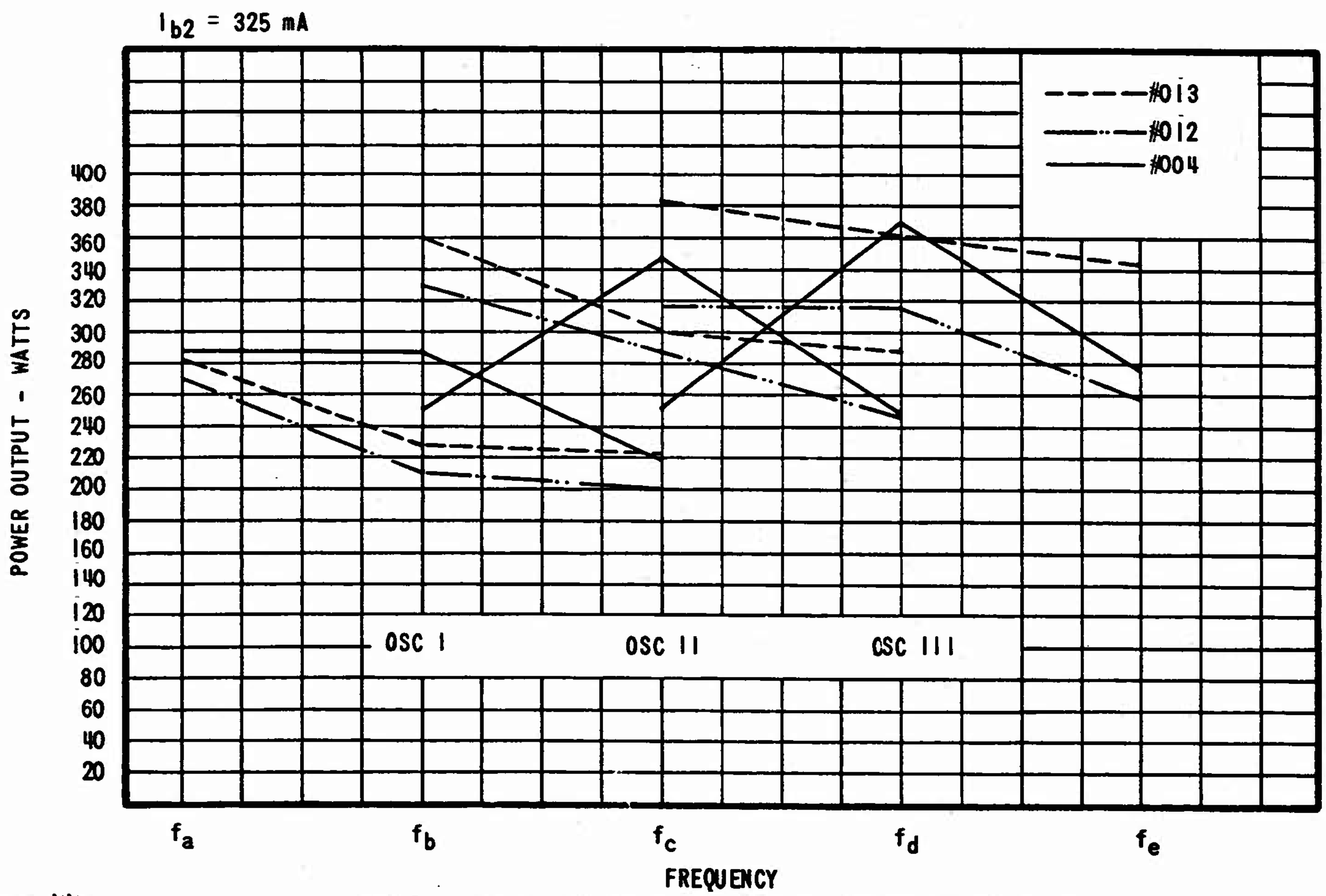


FIGURE 44 QKA 851 SOLE TUNING PERFORMANCE AFTER SHOCK TEST
POWER OUTPUT vs. FREQUENCY

Figure 45 shows the transient time characteristics for tube #13 in which frequency is plotted against time.

(2) Thermal Frequency Drift Tests

The specifications state:

A maximum thermal frequency drift of 1/4% of fe (1/4% x 1850 Mc = 4.625 Mc) shall not be exceeded for any combination of anode inlet temperature from -54°C to +100°C and ambient temperature from -54°C to 85°C. The frequency difference between the maximum and minimum frequencies measured under the four conditions of the test shall not exceed 4.625 Mc. The conditions are as follows:

(a) Under the condition of anode inlet coolant temperature and tube ambient temperature of 30° $\pm$ 10°C, the tube oscillation is stabilized at fe (Oscillation V). The tube is stabilized when the frequency difference between the maximum and minimum frequency measured over a period of one hour at five minute intervals shall not exceed 4.625 Mc.

(b) With the voltages maintained at fe, the tube ambient temperature is to be adjusted to +85°C and the anode inlet coolant temperature to 100°C. After the frequency has stabilized, the measured value is noted as fe1.

(c) The tube ambient temperature is then adjusted to -54°C and the anode inlet coolant temperature to -54°C. The stabilized frequency is then fe2.

(d) Step (b) is repeated except with the tube ambient temperature at -54°C and the anode coolant temperature at +100°C. The stabilized frequency is called fe3.

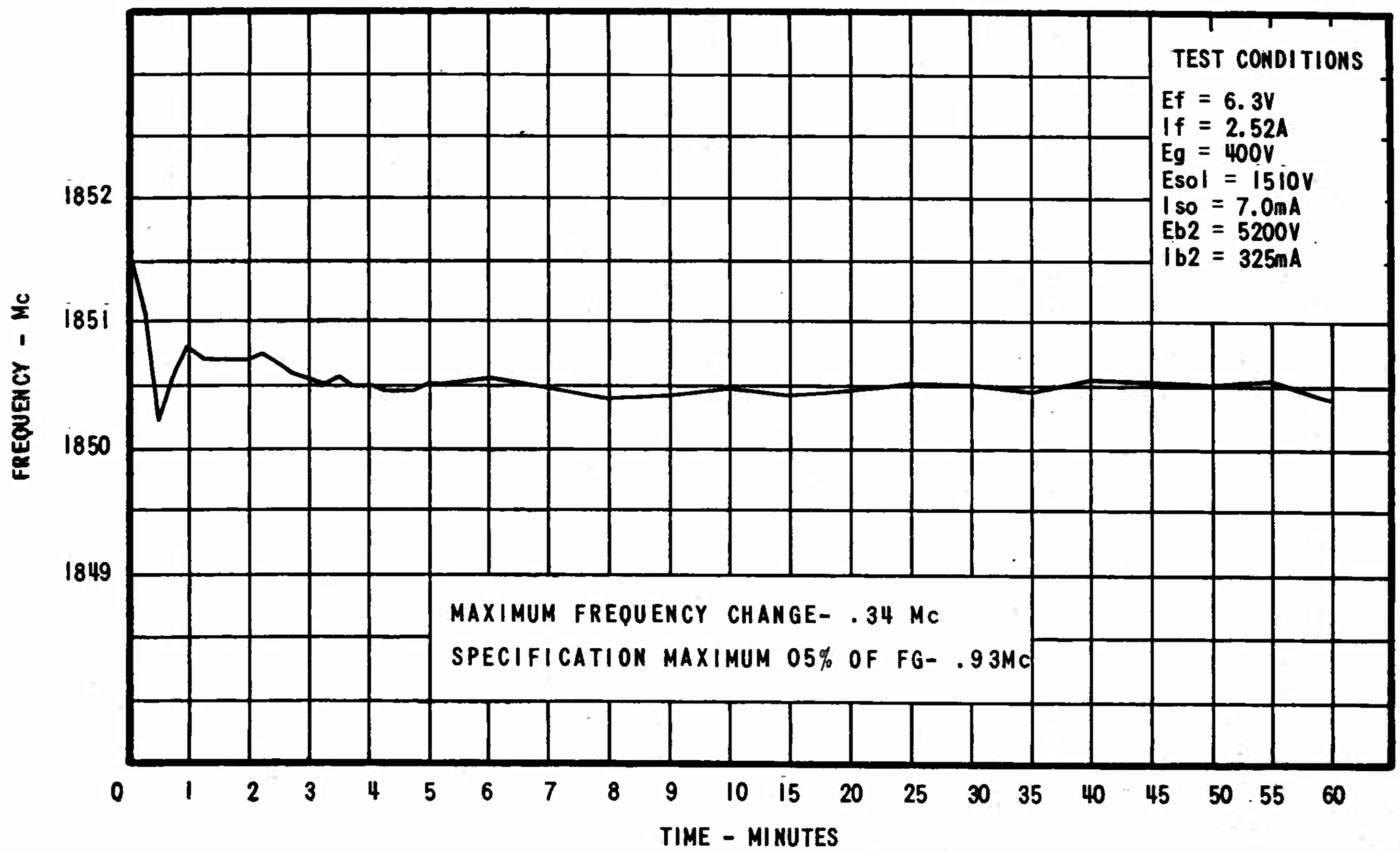


FIGURE 45 QK 851 NO.13 FREQUENCY TRANSIENT TIME

The same three tubes which had passed the transient time tests were given the thermal frequency drift test. All three tubes met the specified requirements.

The first tube drifted a maximum of 2.2 Mc; the second tube drifted 2.7 Mc and the third tube drifted 2.2 Mc.

Figure 46 shows the thermal frequency drift characteristics for tube #13, in which frequency is plotted against oil temperature.

d. Vibration Tests

(1) Operational Vibration

The operational vibration specifications require that:

(a) The tube will be vibrated at an acceleration of 2G or a double amplitude of .06 inch, whichever is limiting, from 5 to 1500 cps.

(b) The vibration frequency range shall be traversed from 5 to 1500 to 5 cps in a twenty minute period while the tube is operating CW at fe (1850 Mc).

(c) At tube resonances, the tube is to be vibrated for fifteen minutes and then shall pass Oscillations I through IV.

(d) The vibration cycle is to be repeated in each of three mutually perpendicular planes as specified by the electron tube outline drawing.

(e) The tube shall pass the electrical requirements of the specification after this test.

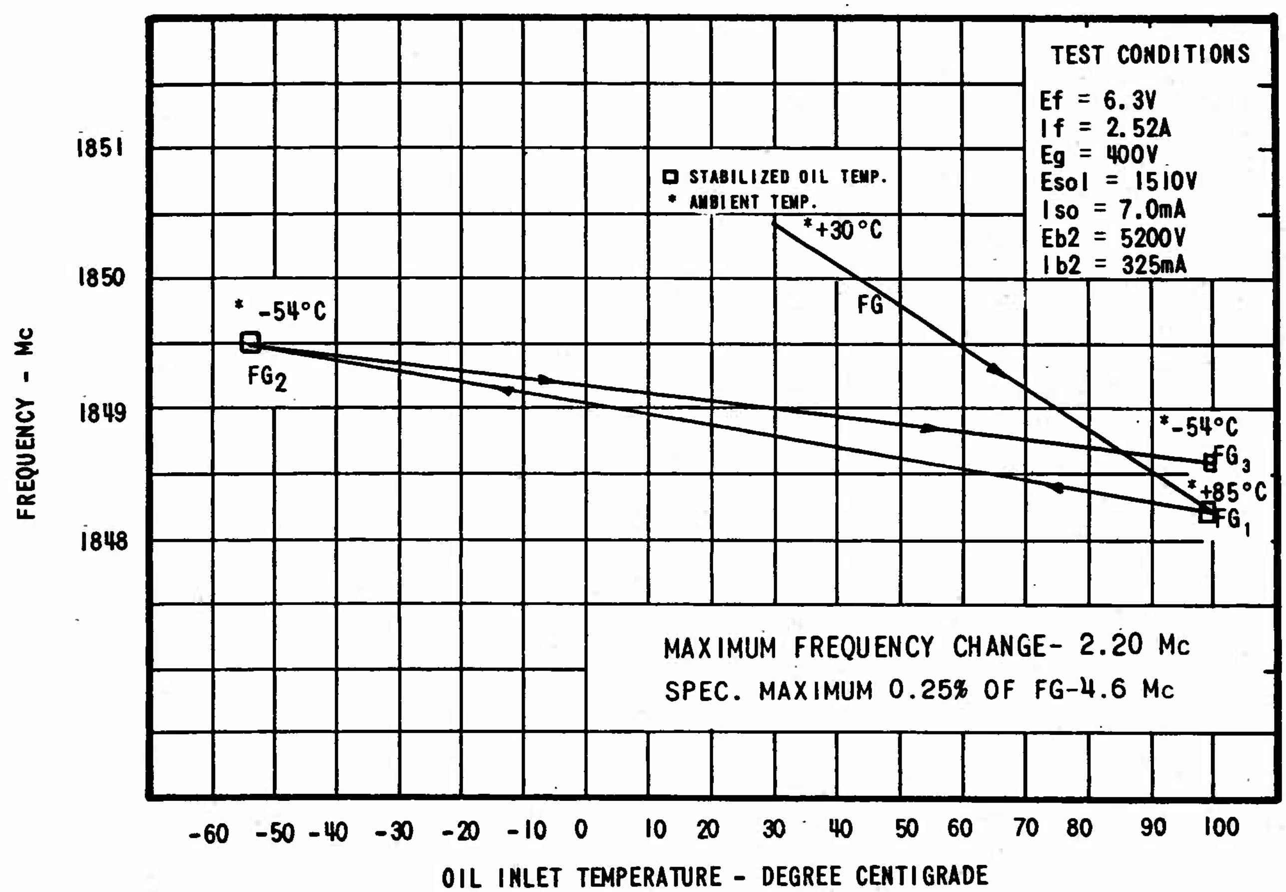


FIGURE 46 QK 851 NO.13 THERMAL FREQUENCY DRIFT

Three tubes were vibrated under operational conditions during this period. The first tube, #13, was vibrated first in the X-2 plane where the direction of vibration is parallel to the output length, and was then vibrated in the X-1 plane, where the direction of vibration is perpendicular to the output length. No deterioration in tube performance was observed. On the Y-1 plane, in which the tube assumes an upright position and the vibration is along the axial (through header) length of the tube, a grid-to-sole short circuit developed. The remainder of the vibration tests (cold non-operational conditions) were conducted without voltages on the tube, first the 5G and the .06 inch displacement vibration in the Y-1 plane and finally the X-1 and X-2 planes at 5G and .06 inch displacement. Monitored heater resistance indicated that an intermittency occurred in the Y-1 plane.

The tube was opened and analyzed, and it was found that one of the grid supports had given way at the grid weld where the material had become brittle from the excessive heat of the welder. The loose grid, free to move with one of its supports disconnected, accounted for the open heater. Tighter controls were instituted to insure more adequate welding procedures and thereby to prevent similar occurrences.

The second and third tubes subjected to this test passed electrical requirements thereafter, and withstood the vibration without incurring any mechanical damage.

Figure 47 shows a plot of the 325 mA anode tuning data for tubes #15 and #19, after operational vibration tests,

(2) Non-Operational Vibration

The non-operational vibration requirements are divided into two parts, low frequency and high frequency vibration. The requirements are as follows:

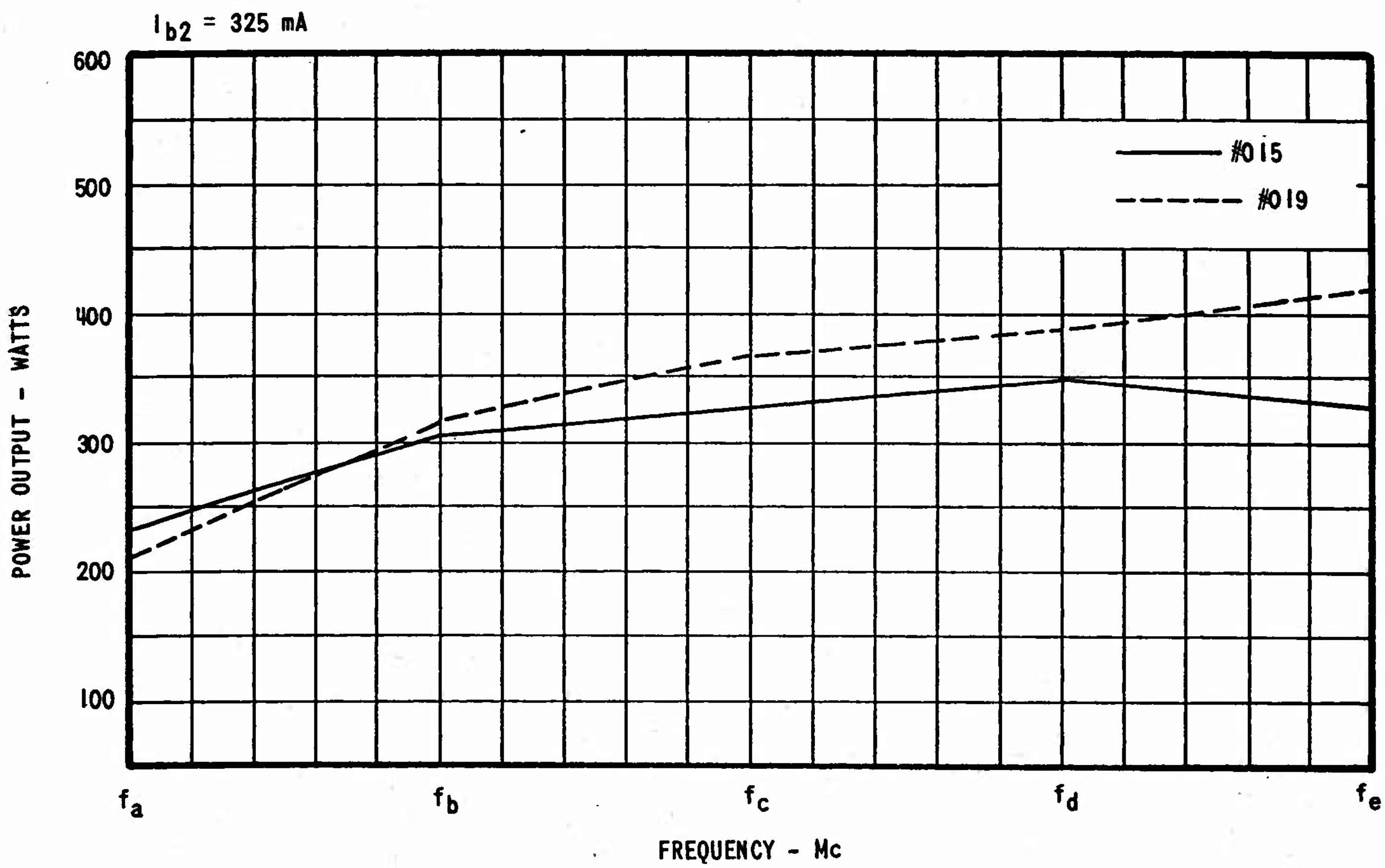


FIGURE 47 QKA 851 NO.15 AND 19 ANODE TUNING
POWER OUTPUT vs FREQUENCY AFTER OPERATIONAL VIBRATION

(a) Low Frequency

The tube is to be vibrated without voltages through the range of 5 to 55 cps at a period of one minute and an excursion of .06 inch, in the specified three planes. Total test duration is to last 100 minutes.

(b) High Frequency

The tube is to be vibrated without applied voltages 55 to 1500 cps at a period of 20 minutes and an acceleration of 5 G in three specified planes for 12 cycles. After each test, the tube is to meet the requirements of Oscillations I through IV.

Three tubes were subjected to the non-operational vibration both at high and low frequencies. These same tubes had been given the operational vibration test prior to undergoing non-operational tests.

The first tube developed a grid-to-sole short circuit, which was attributable to a faulty grid support weld. Correctional measures have been instituted to exercise tighter controls on the welding procedure. A further description of the vibration problems encountered on this tube was given in section d(1), operational vibration.

The second tube was vibrated successfully in the X-1 plane after having passed the operational vibration test. In the X-2 plane, however, the tube developed a short circuit between the accelerator and the grid. Upon further investigation, it was discovered that the accelerator support had pulled away from the accelerator at the support leg weld. To prevent similar recurrences on later tubes, tighter welding controls were instituted.

The third tube, QKA851 #15, passed both operational and non-operational tests without encountering electrical or mechanical problems. The anode tuning data are shown plotted in Figure 48.

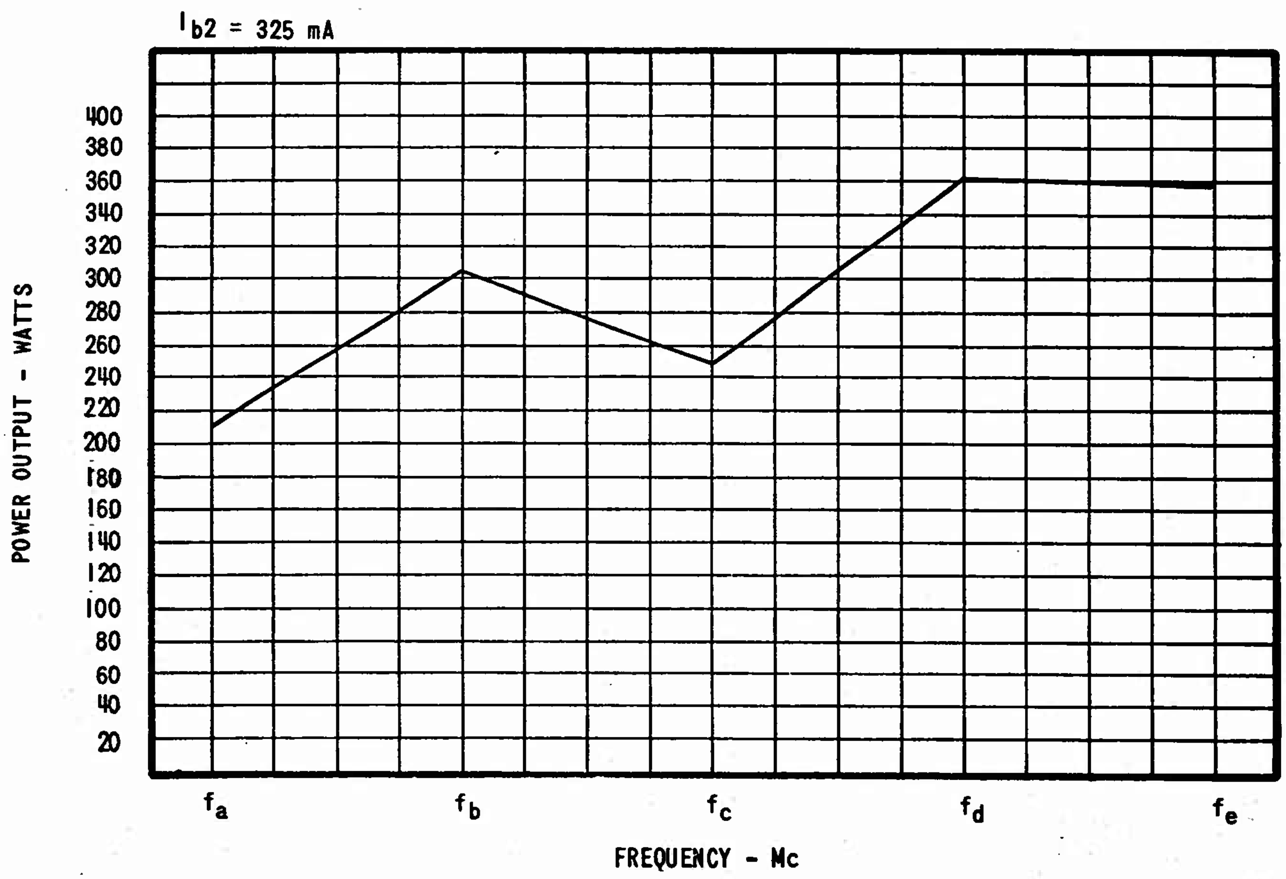


FIGURE 48 QKA 851 NO.15 ANODE TUNING PERFORMANCE AFTER NON-OPERATIONAL AND OPERATIONAL VIBRATION TESTS POWER OUTPUT vs ANODE VOLTAGE

e. Life Tests

Life test requirements state that the tube is to run a minimum of 400 hours at the highest applicable beam current, during which time the tube is to be operated for equal periods at Oscillation I and Oscillation III. Operation of the tube shall be alternated between these oscillations at least once every 48 hours. The load VSWR is to be 1.5, which is to be cycled through all phases continuously at a rate of four cycles per hour. The operating cycle shall be consecutively:

(1)	Heater preheat	60 seconds maximum
(2)	Oscillation	30 minutes maximum
(3)	No voltages	5 minutes maximum

Time assignable to life is to be cumulative oscillation time. All voltages except the heater voltage are to be applied simultaneously.

At the end of the test, the following limitations are imposed on the electrical characteristics:

	Min.	Max.
Eb1	________	2000 volts
Ib1	________	+ 4 mA
Ig	-4 mA	+ 4 mA
Po	80% of initial value before test started	--------

Three tubes were subjected to life test. The first of these tubes QK851 #3, operated under the specified test conditions for eleven hundred hours without indications of deterioration in performance. Figure 49 shows the sole tuning characteristics before and after life test with power output plotted aginst frequency. At the end of this test, it was also observed that the limitations imposed on the electrical characteristics by the specifications were not exceeded.

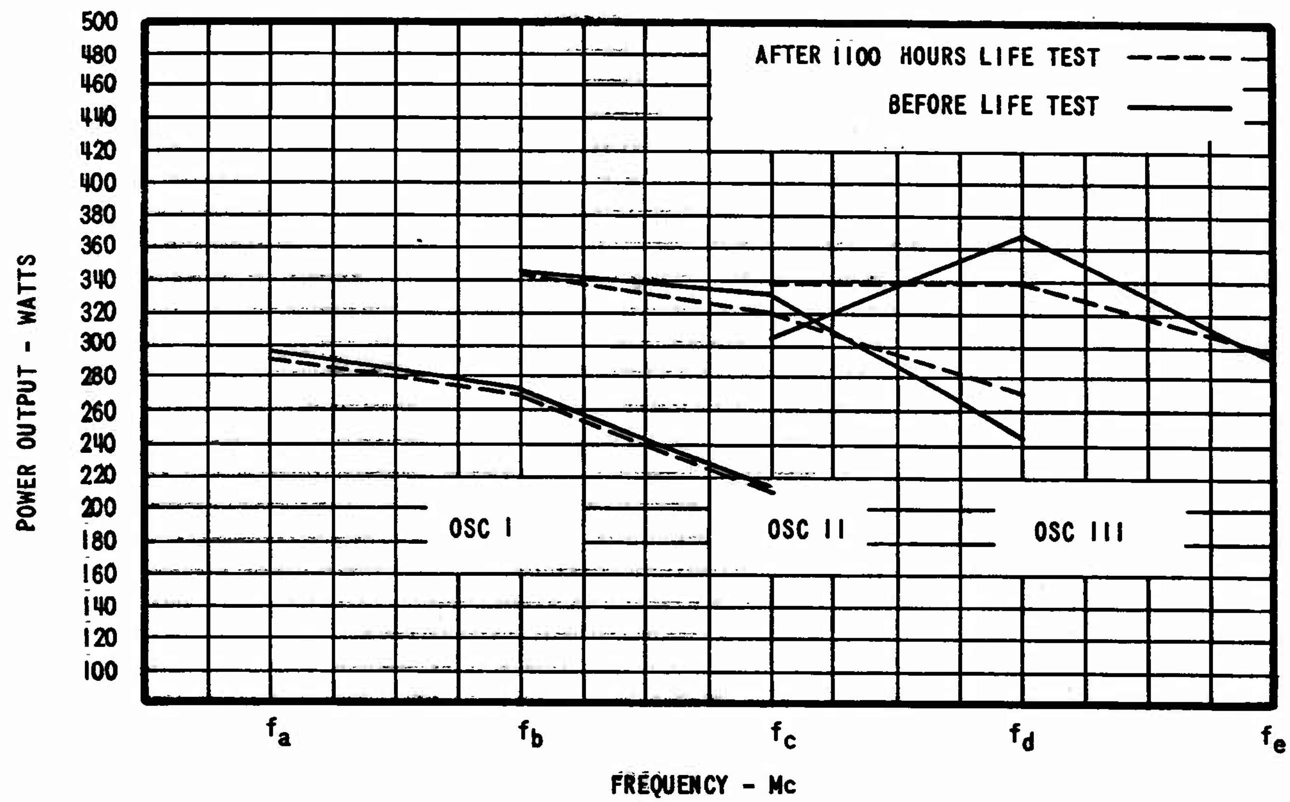


FIGURE 49

QKA 851 NO.003 HALF BAND TUNING
POWER OUTPUT vs. FREQUENCY

The tube was opened and given a thorough engineering analysis. There were no indications of excessive heating of the tube elements or spewing from the cathode, and, in general, the tube exhibited exceptional cleanliness.

The second and third tubes, #4 and #12, were given the four hundred hour test and then were electrically tested. Tests conducted on both tubes after this time showed that the tubes had not suffered any adverse effects from the prolonged testing. The minimum power output for these tubes under the half band tuning conditions (at 300 mA) is shown in Figures 50 and 51.

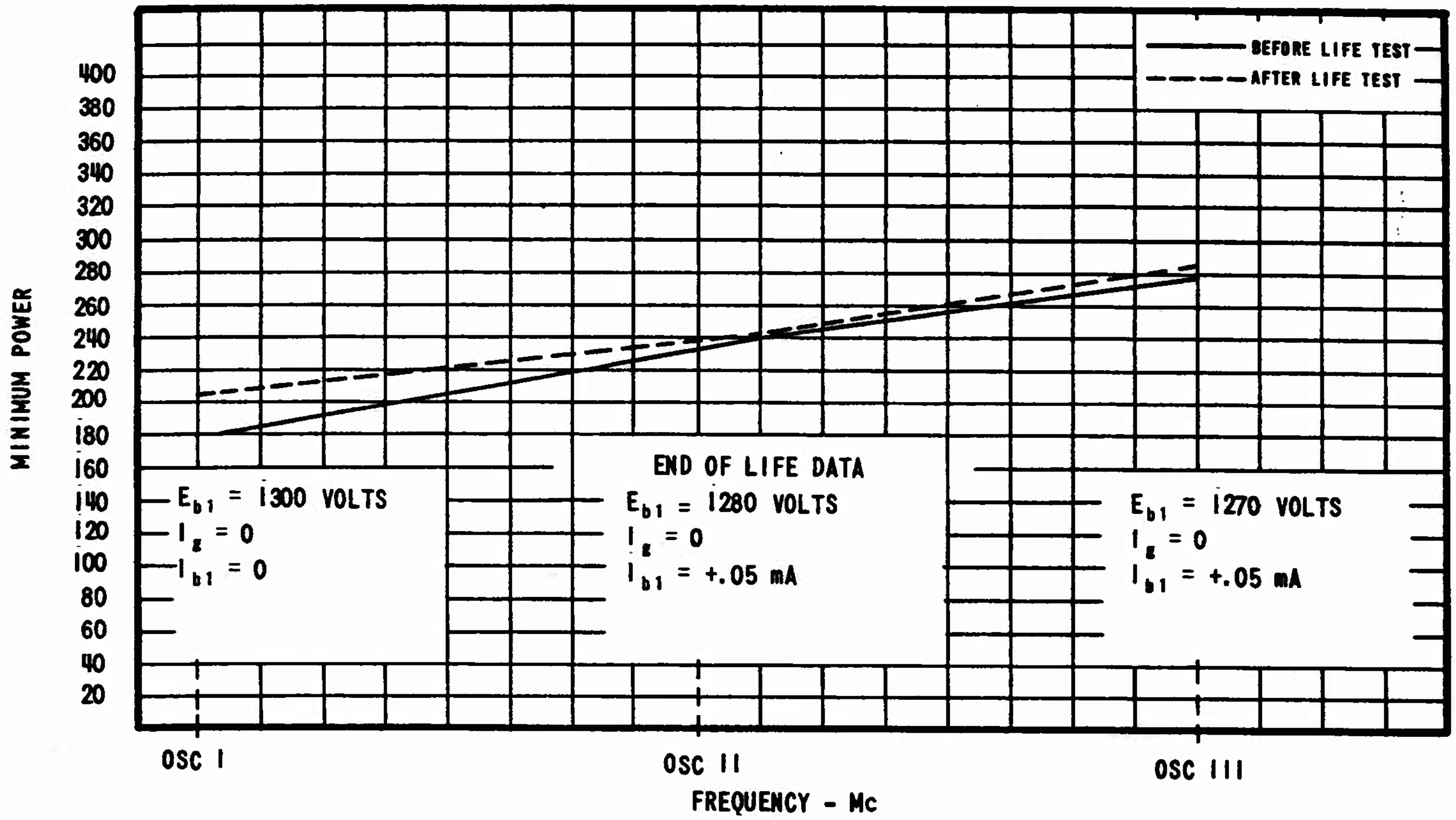


FIGURE 50

QKA 851 NO.004 SOLE TUNING PERFORMANCE
BEFORE AND AFTER 416 HOURS LIFE MINIMUM POWER vs. FREQUENCY

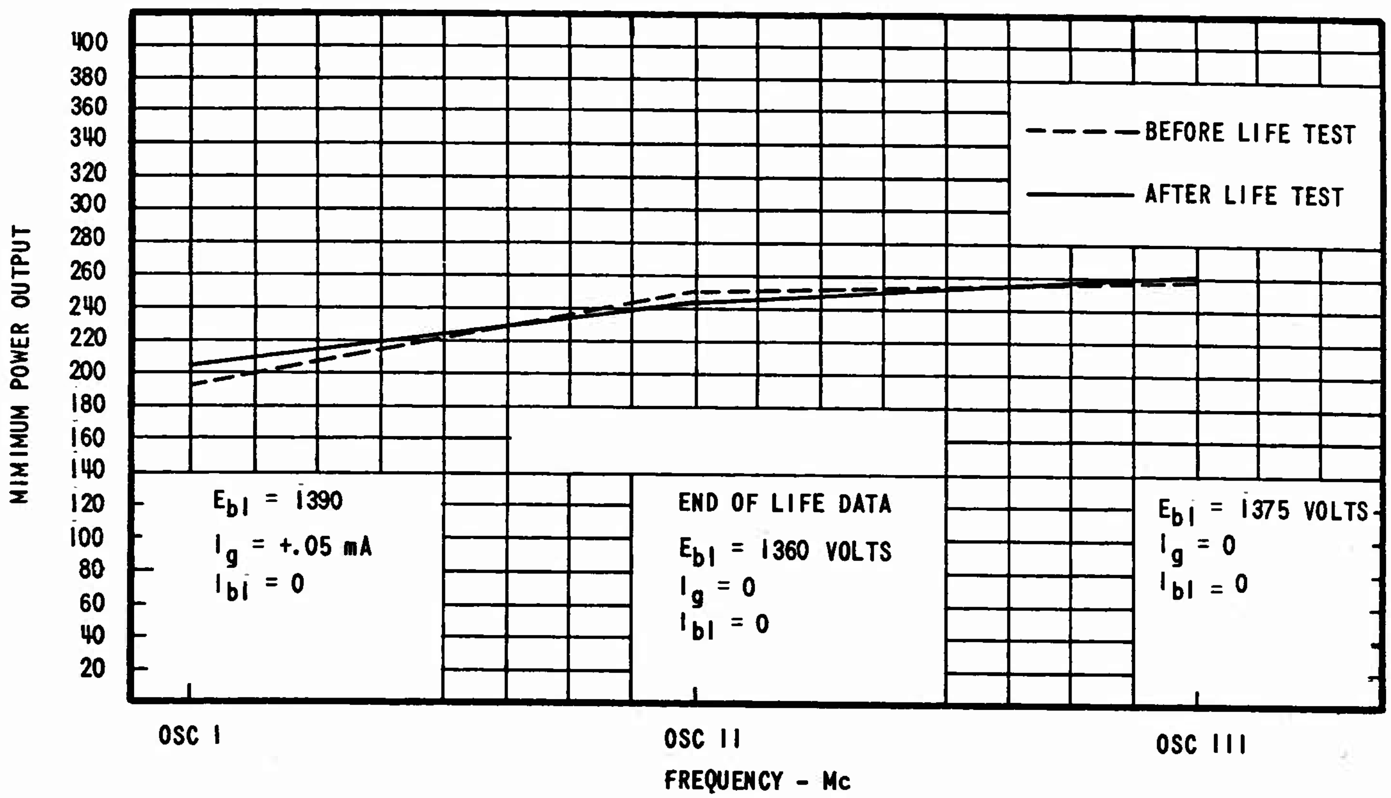


FIGURE 51 QKA 851 NO.012 SOLE TUNING PERFORMANCE BEFORE AND AFTER 410 HOURS LIFE MINIMUM POWER OUTPUT vs FREQUENCY

3. QKA852

a. Electrical Results

The initial models constructed during this period were modeled after the final types constructed in Phase I. One modification was introduced, at no extra cost, to improve the output match to the delay line. This involved decreasing the gap between the delay line fingers and the base of the mating crowns to give added capacitance. A graph of the cold test results obtained with this modification, in which the voltage reflection is plotted against frequency, was presented as Figure 12, page 25. The maximum reflection was 19%. The graph indicates improvement over the match obtained in the earlier months of the program when the reflection peaks reached 25%. Furthermore, the plot is typical of those taken of the other tubes constructed during this phase.

Eight QKA852 tubes were built during Phase II. Three of these tubes were plagued by internal short circuits which eventually destroyed their electrical operation. The first of these tubes suffered heater trouble when adjacent turns came in contact with each other, causing localized heating and eventual melting. This short circuiting, however, occurred only after the tube had been tested and had fulfilled all of the electrical requirements. Quality control procedures were tightened to insure that the specified heater turn spacing would be maintained on future tubes.

Another tube developed a sole-to-anode short circuit when the magnetic field was mishandled, causing the beam to melt a section of the delay line which bridged over to the sole element. The tube initially had shown acceptable power but had a borderline spurious signal in its spectrum.

The third tube which developed troubles passed power requirements but had a frequency discontinuity greater than the maximum specified allowance in Oscillation I and Oscillation V. Later, a short circuit occurred

between the delay line and the sole. Investigation disclosed that small particles of getter material, which had been liberated from an overflashed getter, had wedged between the sole and delay line, thereby causing the electrical short circuit.

Subsequent action was taken to eliminate overflashing of getters and to preclude mishandling of the magnetic field on future tubes.

Five tubes passed all of the electrical requirements. Figures 52 through 54 show the electrical performance for tube #26. Figure 52 shows the 325 mA half band sole tuning data in which power output is plotted against frequency. Figure 53 represents the corresponding 220 mA half band data. Figure 54 shows the anode tuning characteristics in which power output is plotted against frequency. Three tubes meeting the electrical requirements were put to one side and will be delivered to the Air Force when notice of acceptance and approval has been received. (The performance data of these tubes are presented in Tables 4, 5 and 6 of the electrical data section, pages 131, 132 and 133.) The remaining good tubes were subjected to life and environmental tests in accordance with the required specification.

b. Thermal Tests

The thermal frequency drift requirements stipulate that the maximum frequency variation of the QKA852 under the specified conditions is not to exceed 1/4% of fe (1/4% x 2550 Mc = 6.375 Mc) while the transient time requirement demands a maximum change of 1.27 Mc.

Tube #11 was given the thermal frequency drift test and it was found that the maximum change was 7.22 Mc, exceeding the 6.375 Mc allowed by the specifications. This tube passed the transient time test with a change of 1.92 Mc, where the maximum limit is 1.27 Mc.

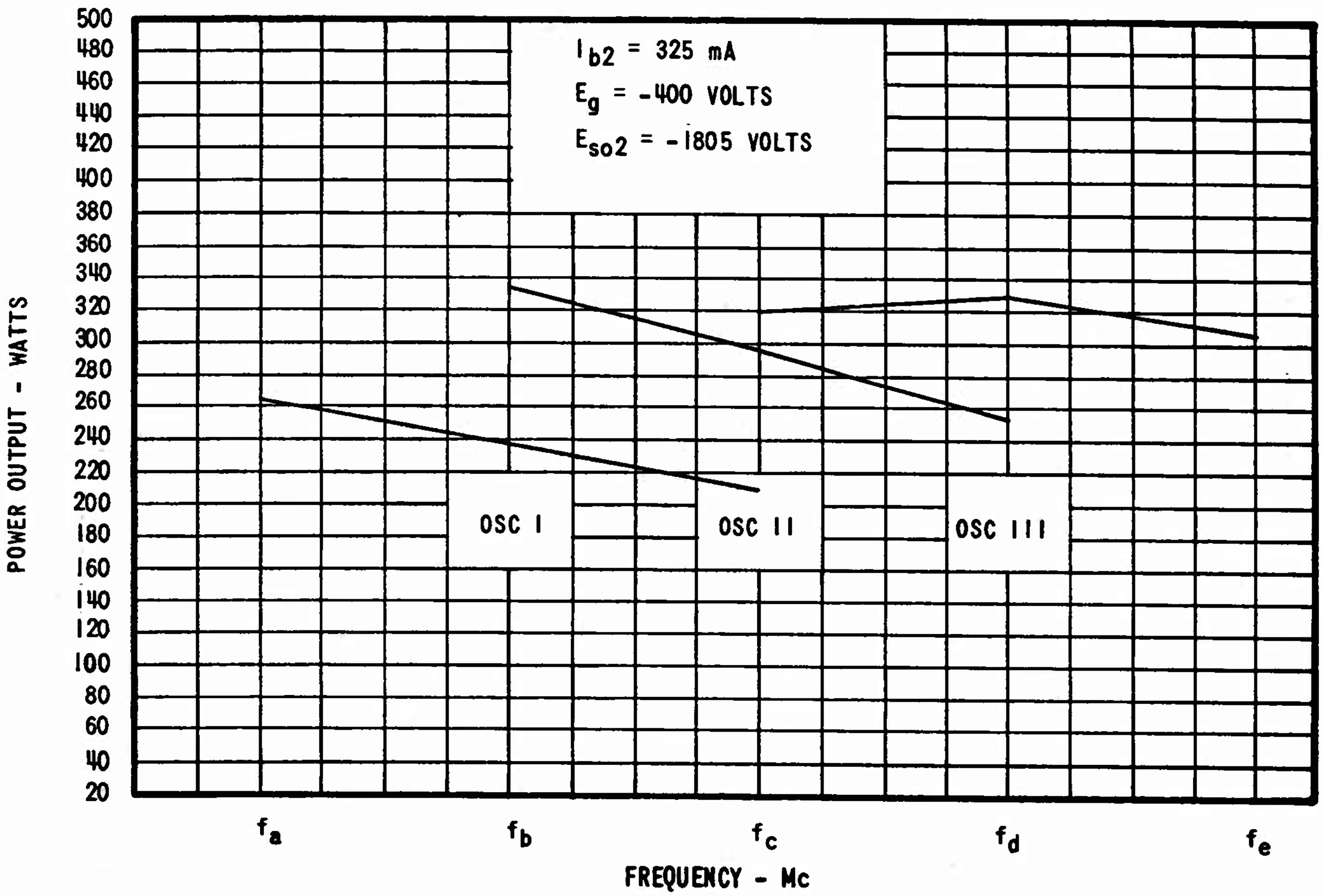


FIGURE 52 QKA 852 NO.26 HALF BAND TUNING POWER OUTPUT vs FREQUENCY

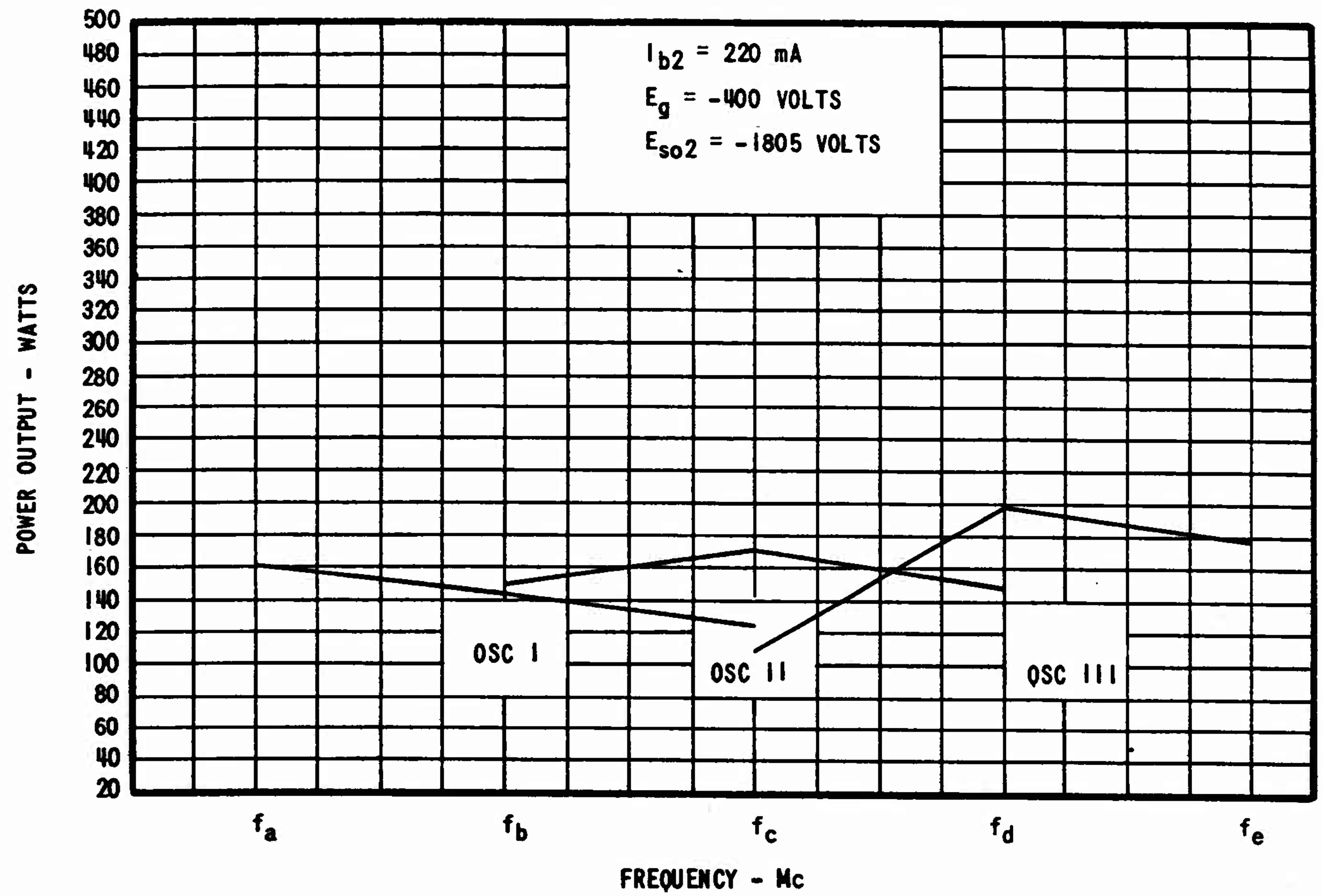


FIGURE 53 QKA 852 NO.026 HALF BAND TUNING POWER OUTPUT vs FREQUENCY

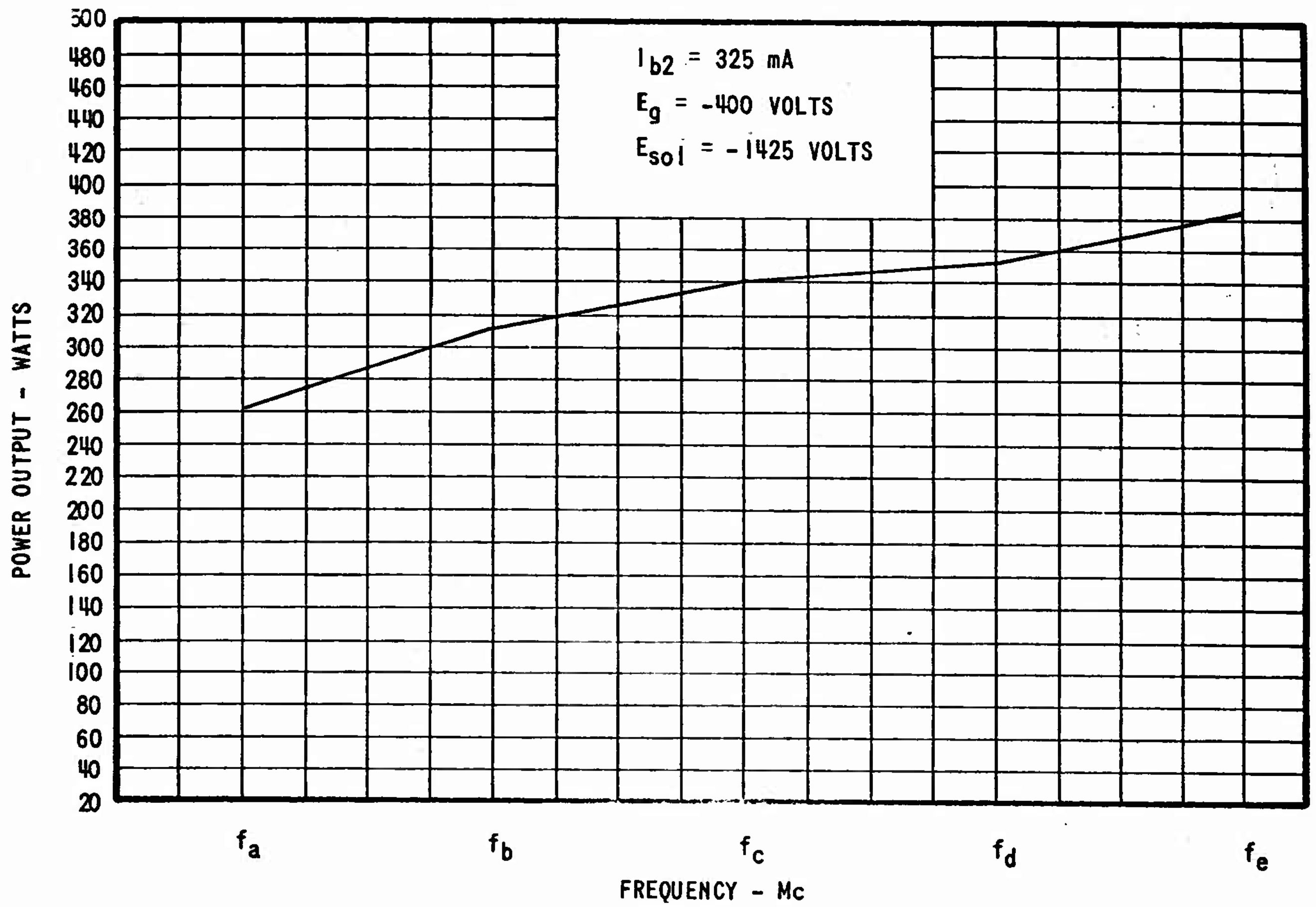


FIGURE 54 QKA 852 NO.026 ANODE TUNING POWER OUTPUT vs FREQUENCY

This tube was again subjected to the thermal tests, this time with a modification in the magnetic compensators. The tube passed both tests, bettering the allowed maximum limits of the transient time test by 12%, and the thermal drift test by 29%. The drift and transient time performance is plotted in Figures 55 and 56. Figure 55 shows frequency versus time after application of delay line current, while Figure 56 shows frequency plotted against oil inlet temperature.

c. Shock Tests

Tube #11, which has passed the thermal tests, was shock tested in the three specified planes without experiencing any changes in electrical operation or without suffering mechanical damage. The anode tuning data (Oscillation V) are plotted in Figure 57.

d. Vibration Tests

Two tubes were given vibration tests. The first tube was one which had been constructed during Phase I and which had not demonstrated completely satisfactory operation. On non-operational vibration at 5G in the Y-1 plane under the high frequency conditions, the tube experienced troubles in the output section. This trouble was detectable inasmuch as voltage reflection readings were being taken while the tube was vibrating. During the vibration, the reflectometer indicated rapid deflections and finally the reflection increased to ninety percent. Analysis on the tube showed that the output center conductor had broken away from the output finger at the weld.

In order to strengthen this connection, it was decided to construct subsequent tubes with a brazed output-conductor - 1st finger.

The second tube to be given vibration tests incorporated this modification. The tube passed all vibration tests, both operational and non-operational, and continued to operate satisfactorily on electrical tests taken afterwards. The data comparing anode tuning performance before and after complete vibration testing are shown in Figure 58.

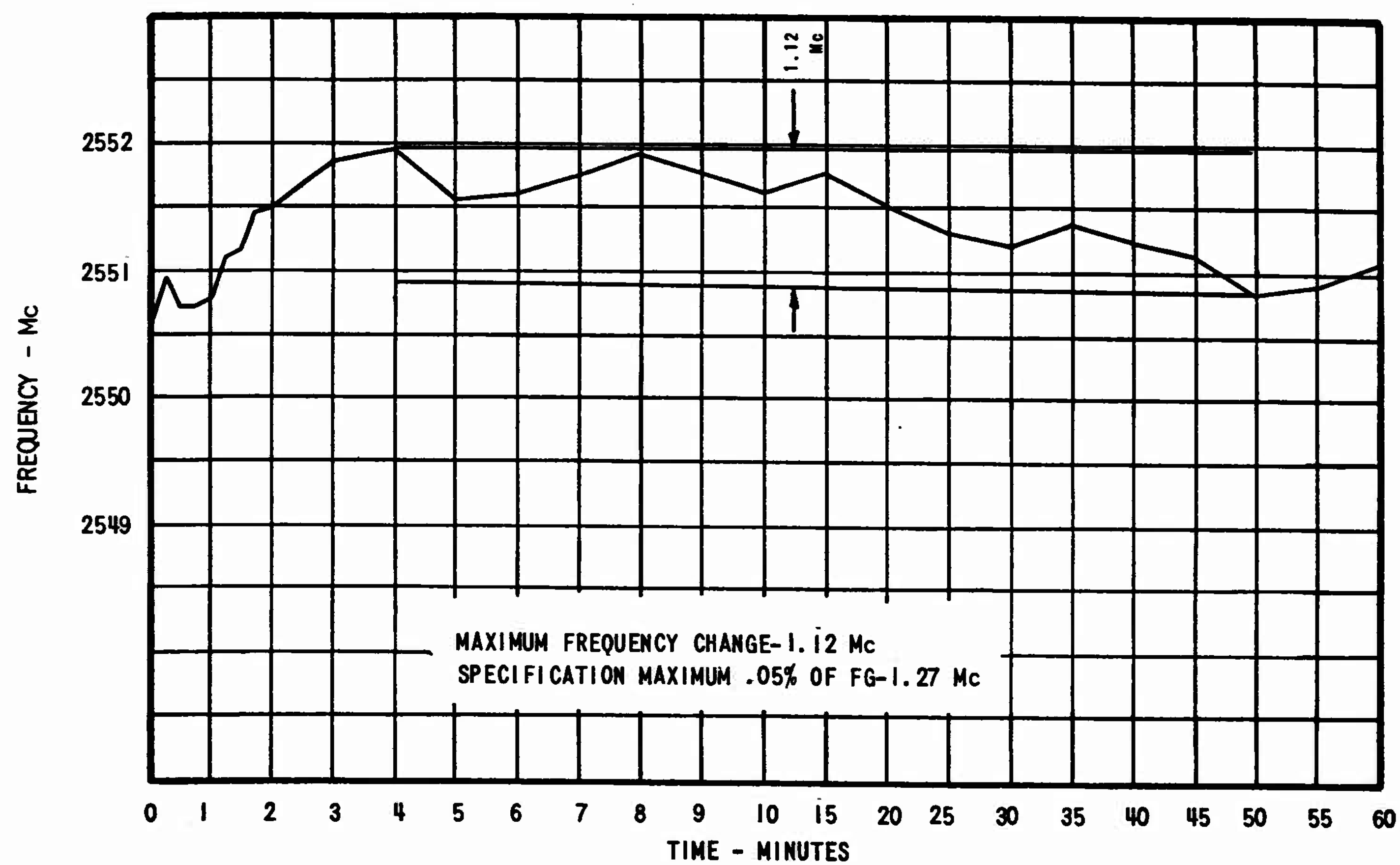


FIGURE 55 QKA 852 NO.11 FREQUENCY TRANSIENT TIME

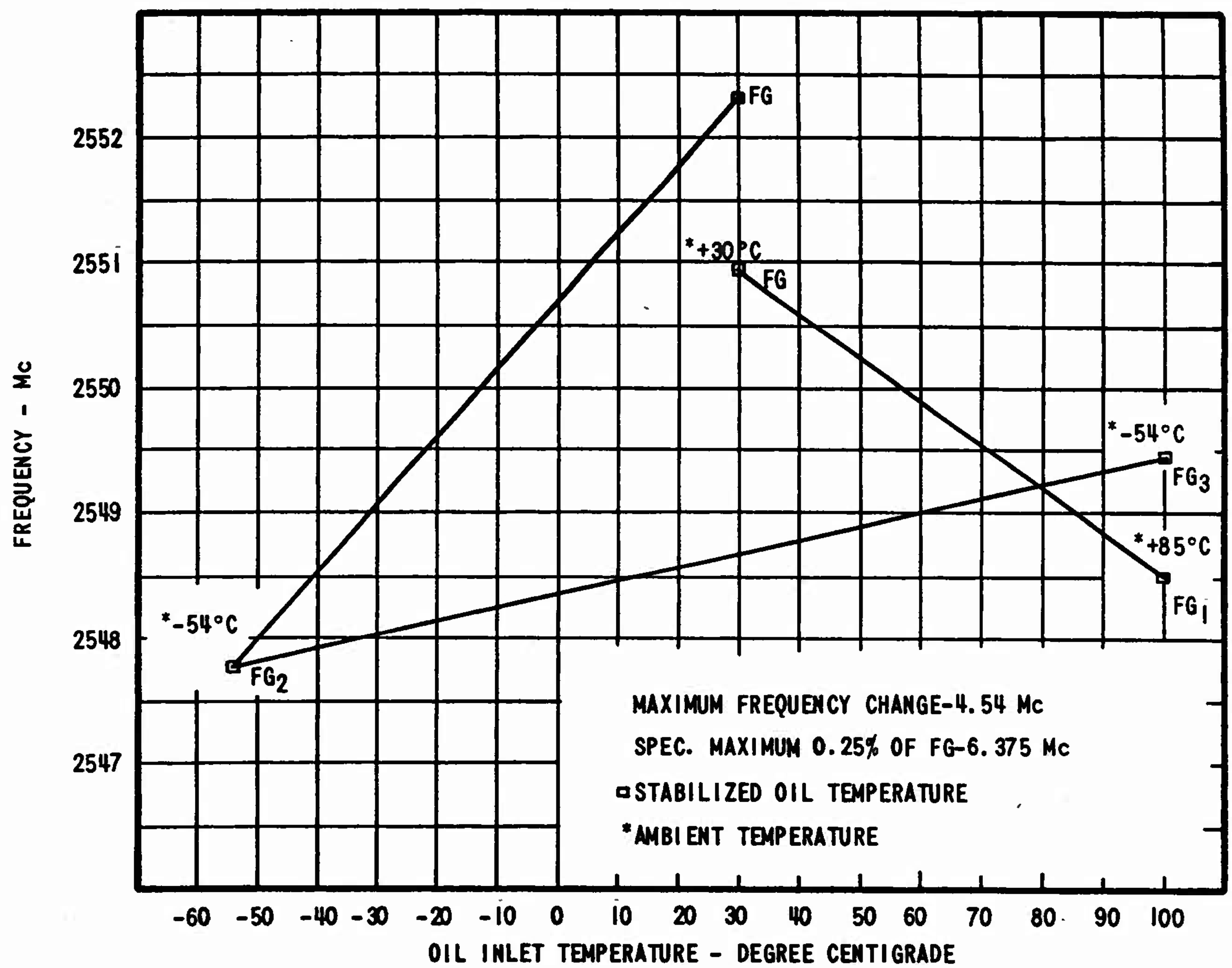


FIGURE 56 QKA 852 NO. 11 THERMAL FREQUENCY DRIFT

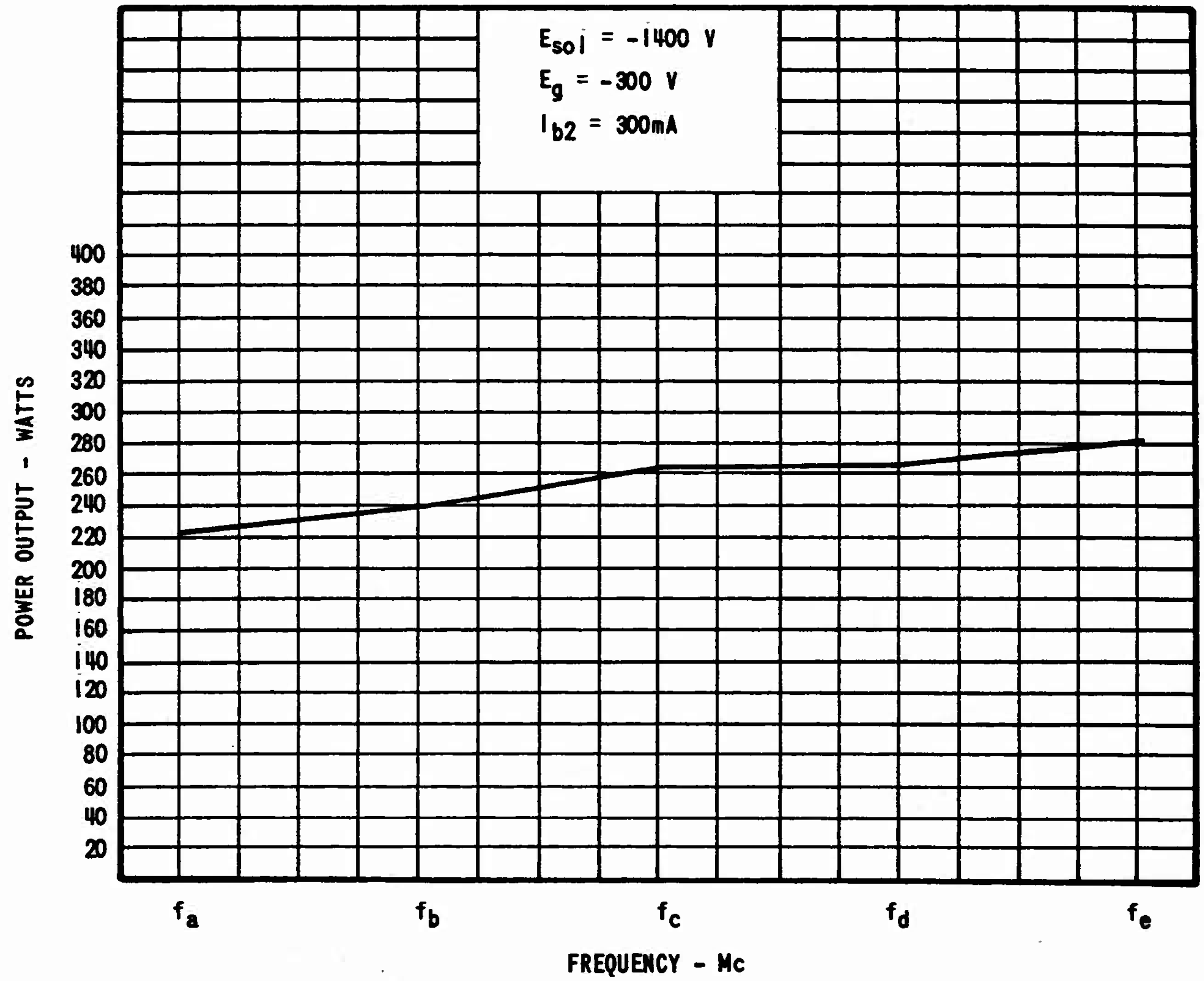


FIGURE 57 QKA 852 NO.011 ANODE TUNING (OSC V) PERFORMANCE BEFORE AND AFTER SHOCK TEST

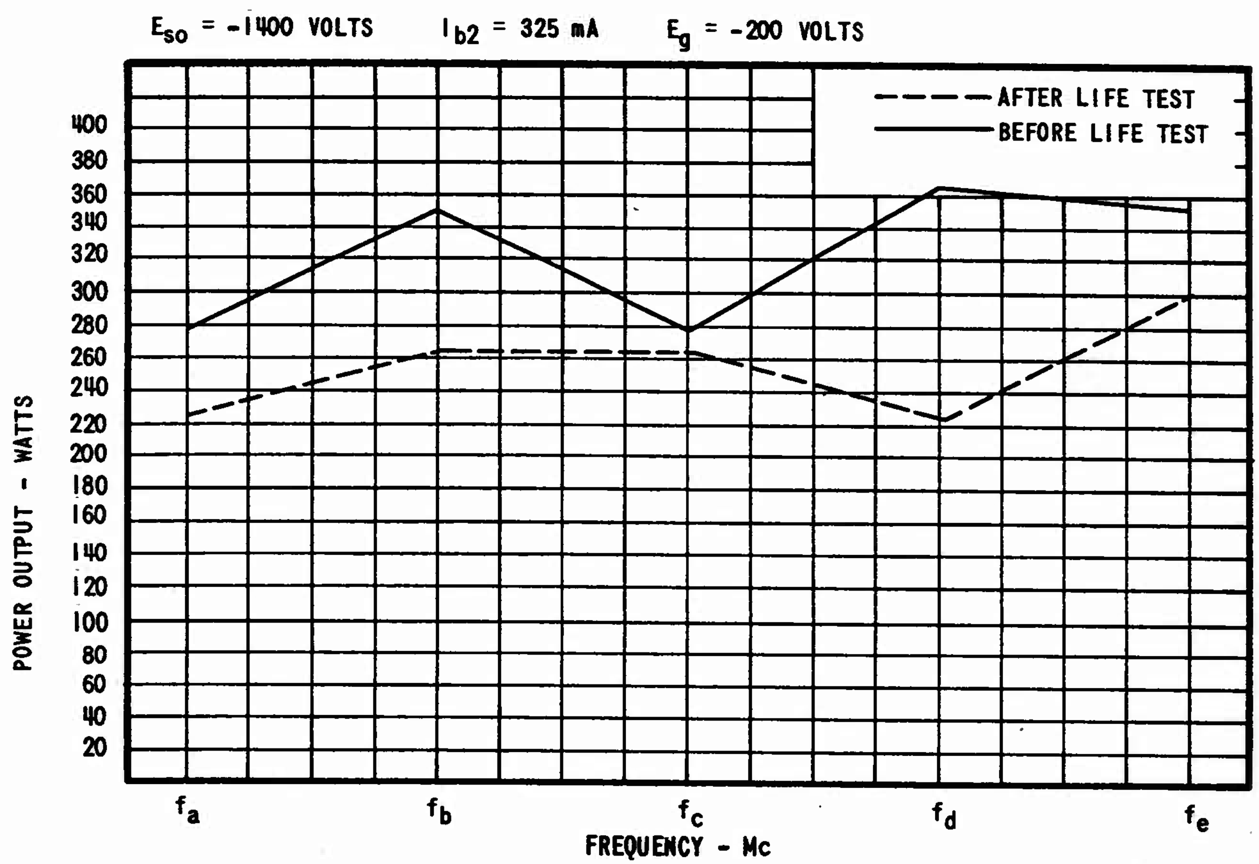


FIGURE 58 QKA 852 NO.027 ANODE TUNING PERFORMANCE BEFORE AND AFTER OPERATIONAL AND NON-OPERATIONAL VIBRATION

e. Life Test

One tube run on life test operated for 856 hours. The test was discontinued when a faulty oil switch on the oil circulator did not activate as the coolant supply became low. Consequently, the tube became overheated and failed. It was learned upon subsequent analysis that the prolonged operation without coolant had produced sufficient heat to open one of the vacuum seals in the coolant circuit, whereupon residual oil was absorbed into the interior of the tube. Other than the deposit of oil, the tube showed no deleterious effects from the life test (which had exceeded the specified minimum running time of 400 hours).

4. QKA855

a. Electrical Tests

At the end of the Phase I effort, it was decided that the higher impedance line was necessary along with an improved thermally dispersive collection system. In addition, it proved advantageous to introduce added attenuation in the active delay line length to suppress spurious signal outputs. Symmetrical cathode end shields had also proved effective in controlling beam leakage.

Tubes were constructed during this period to meet the objective requirements, and six of these tubes passed all electrical tests. Figures 59 through 61 show the power characteristics (power vs frequency) for tube #11 which is one of these six tubes; the data are representative of the lot. Figure 59 shows the 300 mA half band sole tuning performance, Figure 60 the 200 mA half band characteristics, and Figure 61 the 300 mA anode tuning data. In all cases, the power exceeded the specified minimum of 165 watts for the 300 mA operation and 100 watts for the 220 mA operation.

Problems were encountered in three tubes constructed during the period. The first of these tubes passed the electrical portion of the specification with all voltages and currents within the specification limits while operating in an electromagnet, but a subsequently developed sole-to-anode short circuit prevented the taking of data under permanent magnet conditions. Scrap analysis of the tube revealed that this short circuit resulted from a deformation of the exhaust cover. Both the sole and anode covers were strengthened to prevent a recurrence of the problem.

The second tube which developed problems was of essentially the same design as the first. The tube met all of the power requirements with all voltages and currents within the requirements of the specifications, with the exception of the low frequency end of Oscillations I and II. At these points, an anomalous moding condition occurred which was characterized by a power dip. Scrap analysis failed to indicate the reason for the anomalous performance.

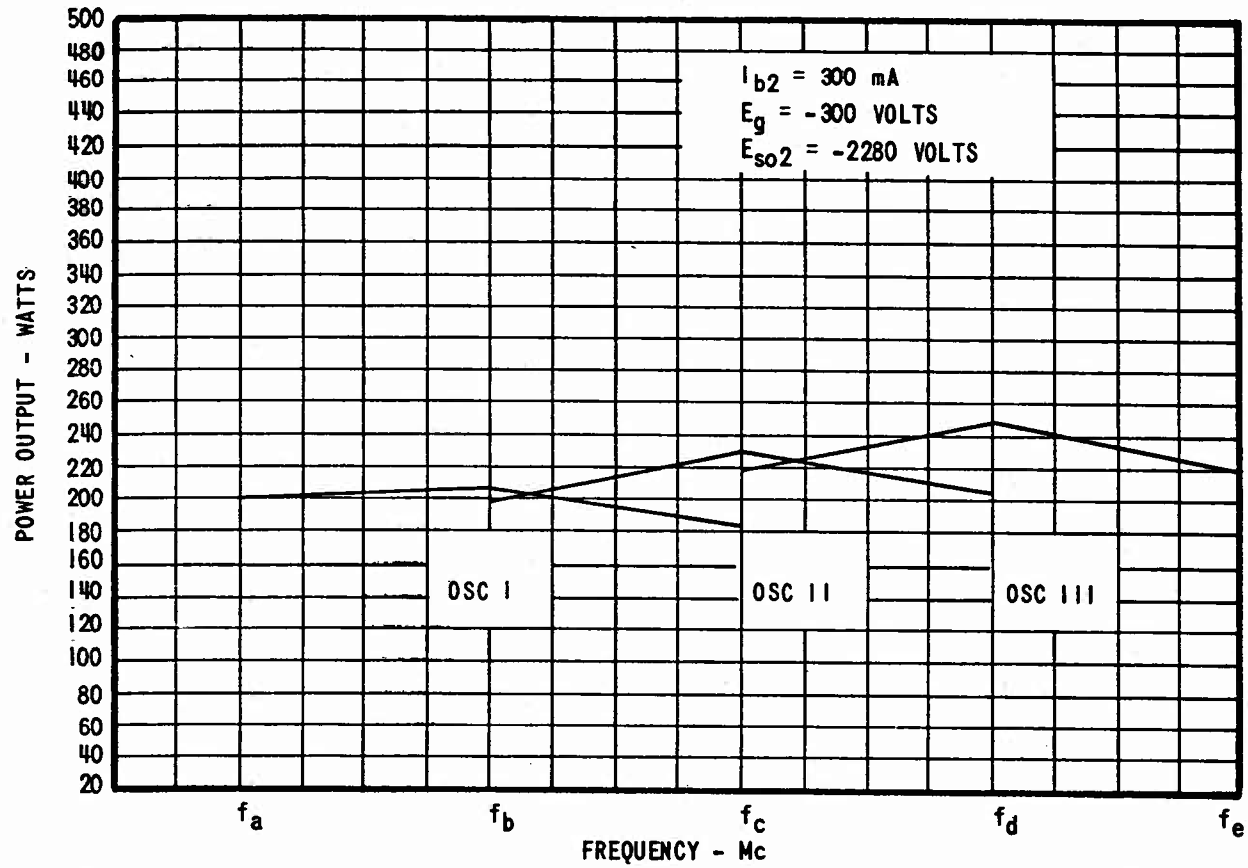


FIGURE 59 QKA 855 NO. II HALF BAND TUNING POWER OUTPUT vs FREQUENCY

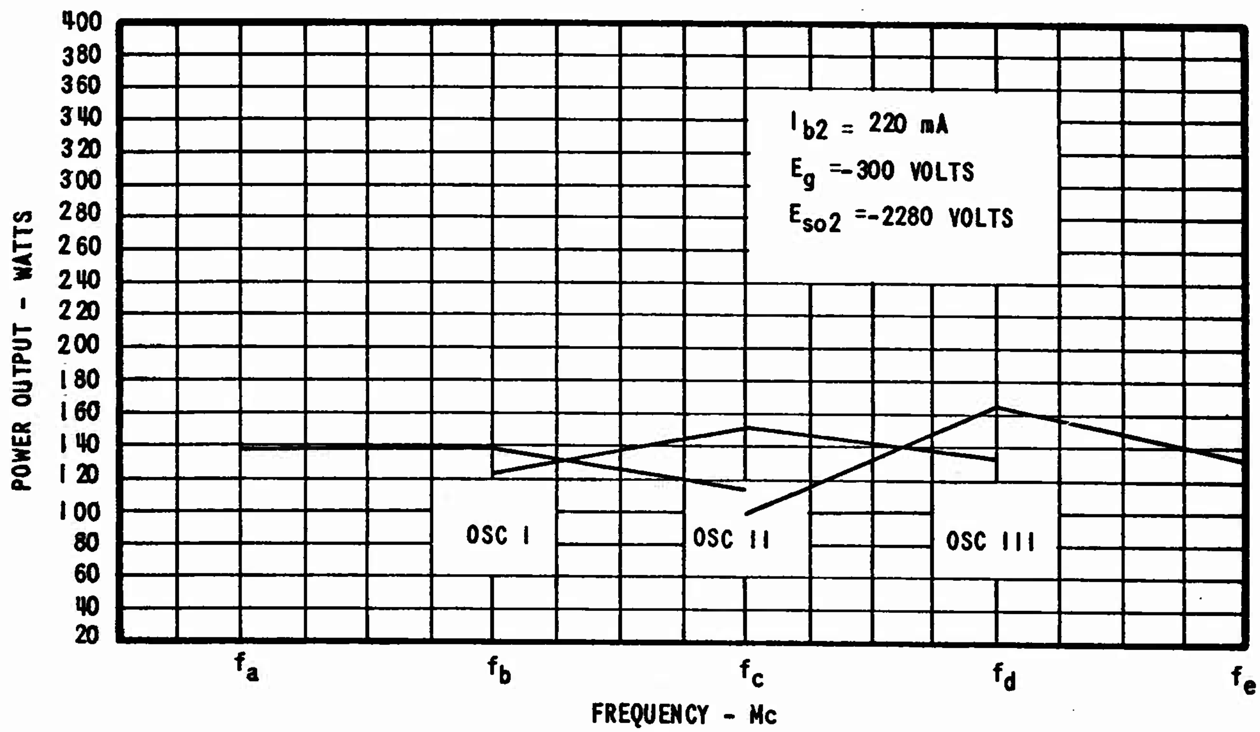


FIGURE 60 QKA 855 NO. II HALF BAND TUNING POWER OUTPUT vs FREQUENCY

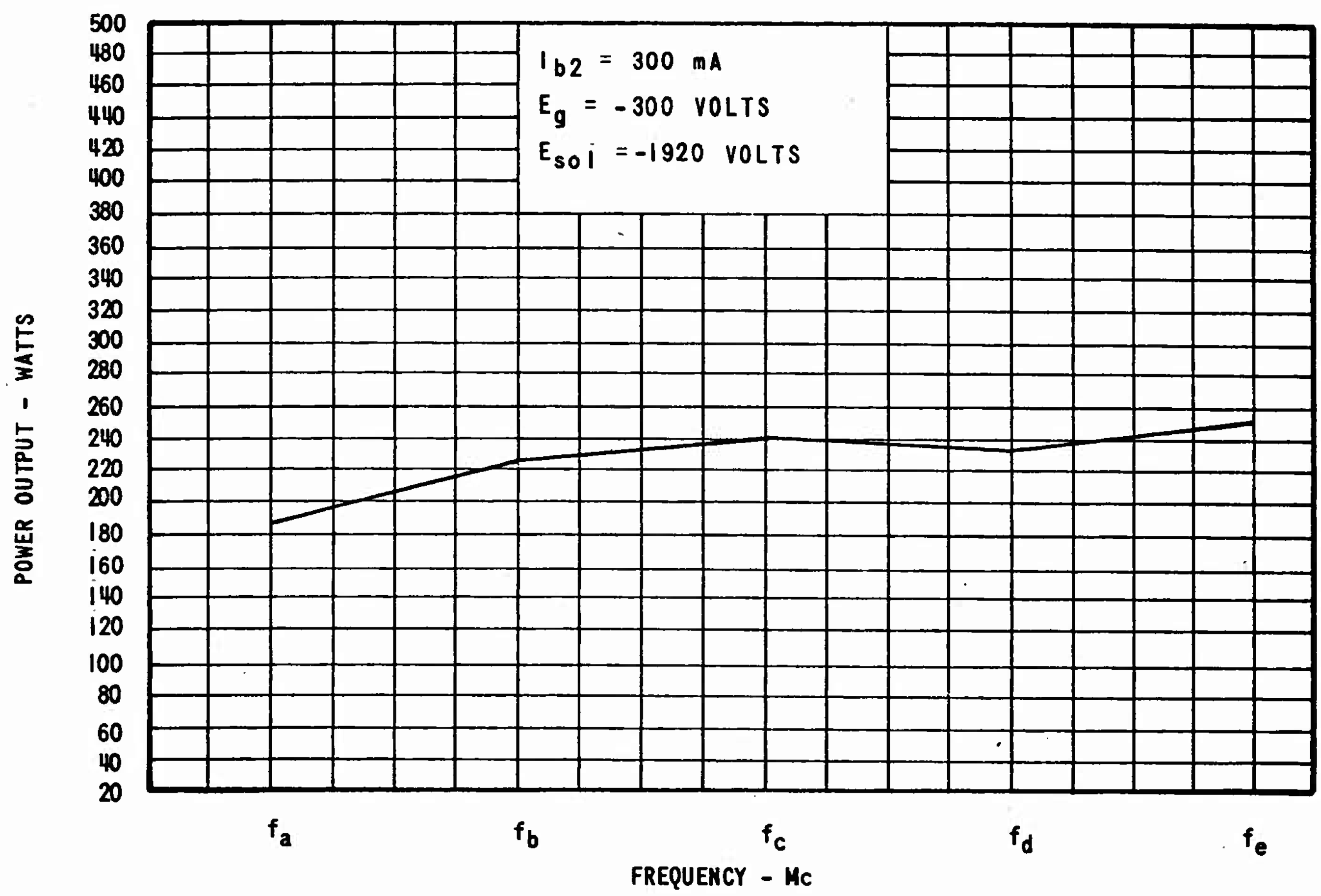


FIGURE 61 QKA 855 NO. 11 ANODE TUNING POWER OUTPUT vs FREQUENCY

The third tube exhibited low power at the high end of each of the three sole tuned oscillations.

After a study of these last two tubes, it was decided that an improvement in the optics would correct the low power problem at the higher ends of the oscillations. By re-locating the electron gun radially towards the anode structure on subsequent models, substantial improvement in tube operation was noted. The remaining tubes which featured this modification met all of the electrical requirements.

Three tubes meeting the electrical requirements were placed to one side and will be delivered to the Air Force when notice of acceptance and approval has been received. The other three good tubes were subjected to life and environmental tests in accordance with the required specifications. (The performance data of these tubes are given in Tables 7, 8 and 9 of the electrical data section, pages 134, 135 and 136.

b. Shock Tests

The shock test requirements of the QKA855 are identical to those of the QKA851, and these requirements are stated under the appropriate section of that tube type.

Three tubes, #11, #14 and #17, were subjected to the 15G shock test in the specified three mutually perpendicular planes. A comparison of the complete electrical data taken before and after testing indicated no noticeable degradation in performance. Figures 59, 62 and 63 show the sole tuning data at 300 mA for these three tubes; the data are identical to that obtained after shock test. A careful scrap analysis made of one tube after all useful information had been obtained from it showed that none of the elements of the tube had suffered any detrimental effects due to this testing.

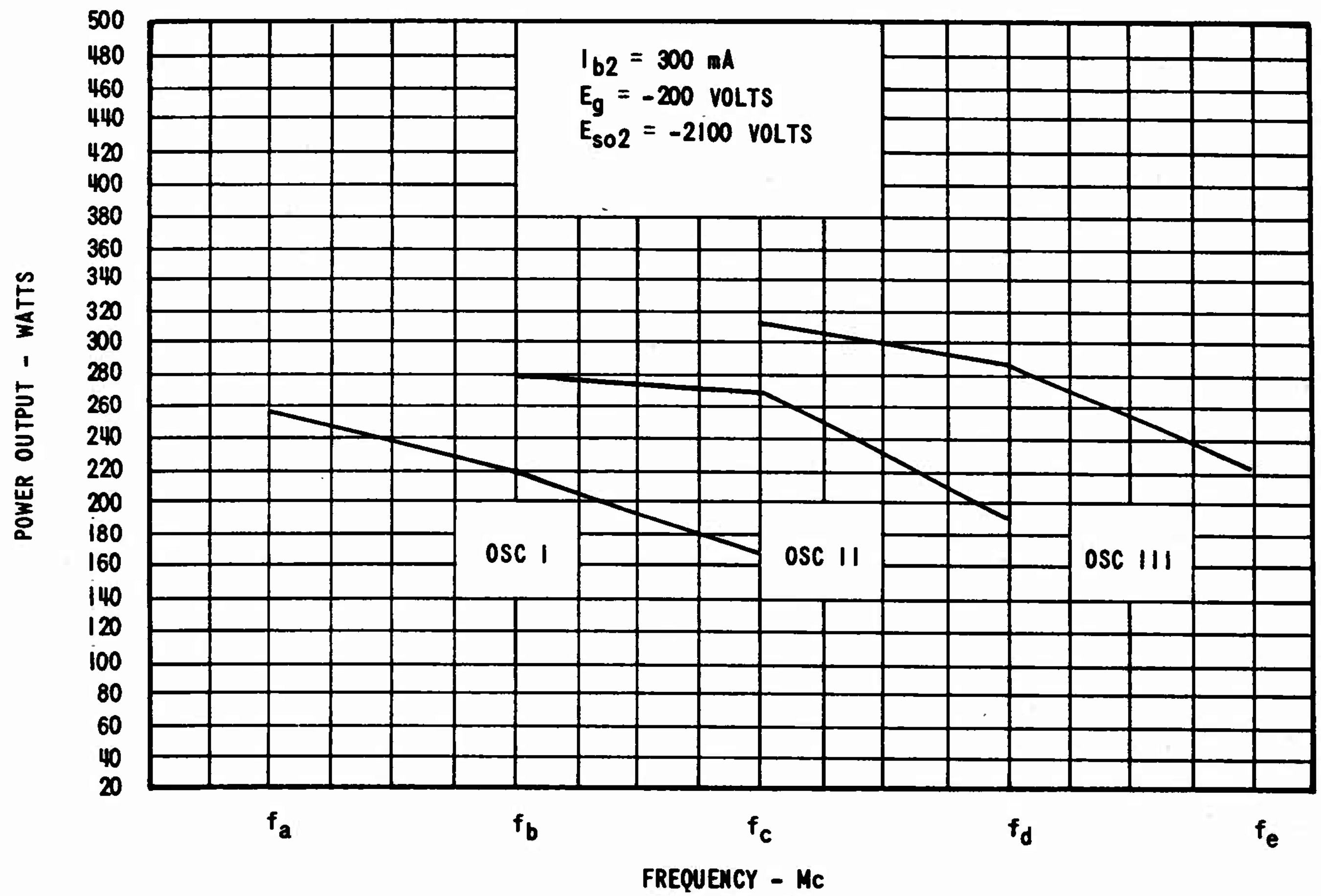


FIGURE 62 QKA 855 NO.014 HALF BAND TUNING POWER OUTPUT vs FREQUENCY

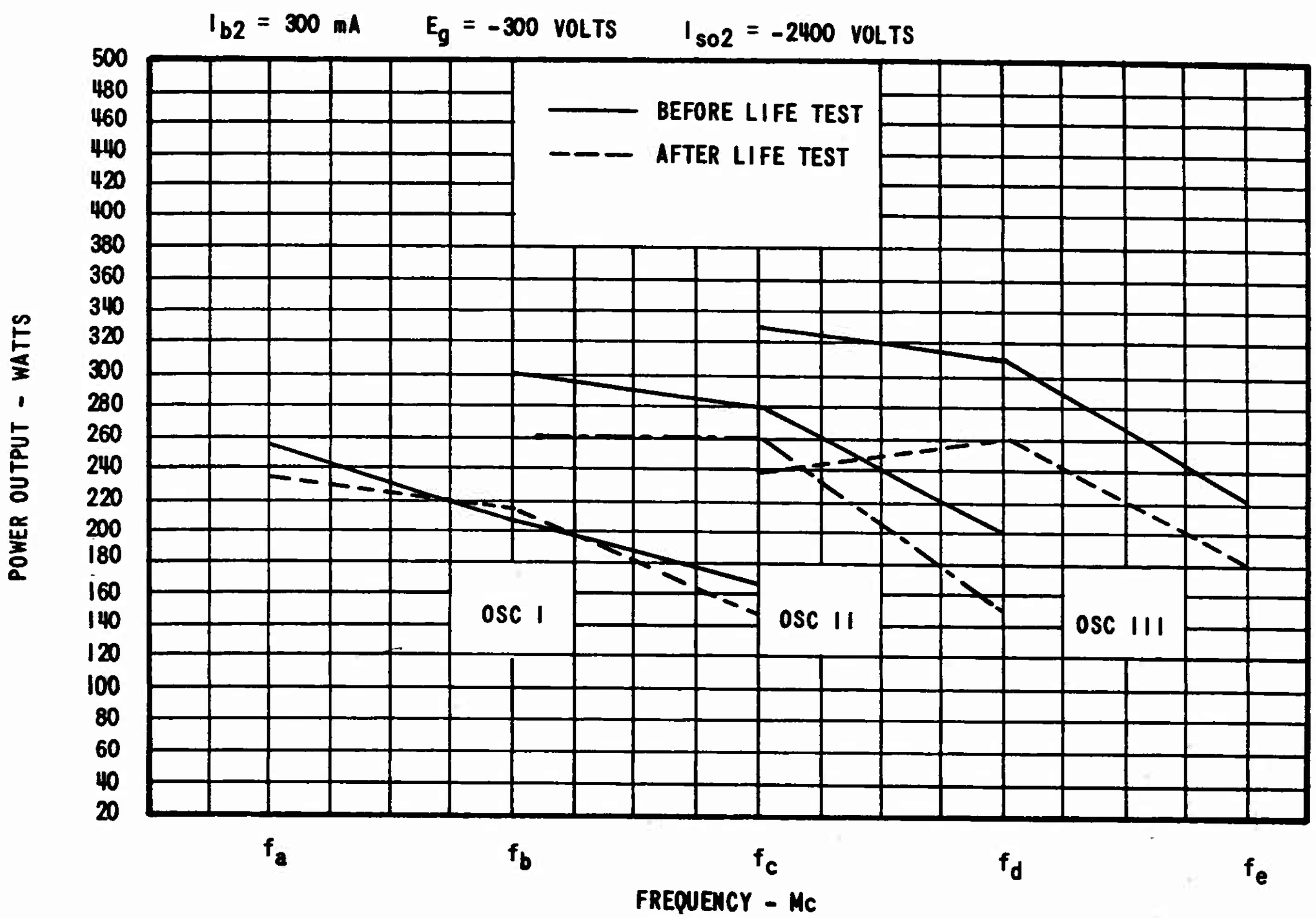


FIGURE 63 QKA 855 NO.017 HALF BAND TUNING POWER OUTPUT vs FREQUENCY

c. Vibration Tests

The vibration requirements for the QKA855 are identical to those of the QKA851 and are stated in the QKA851 section.

Three tubes were given the entire vibration test consisting of the operational and non-operational tests.

Tube #5, an early tube, was operationally tested under the 2G requirements, and, in later tests, it was found to operate satisfactorily. During non-operational vibration tests, the 5G cycling loosened several crown-holding screws with an accompanying shifting of the crowns. Analysis disclosed that all other components of the tube remained unaffected by the vibration. In later tubes, the position of the crowns relative to one another was maintained by introducing a modification in the crown holding screws.

Two other tubes, #14 and #17, were subjected to the complete vibration tests, including both cold and operational conditions, at the high and low vibration frequencies in the three specified planes. No deterioration in performance was observed after the tubes had undergone the complete vibration tests. The data are identical to those represented in Figures 62 and 63.

d. Thermal Tests

The thermal frequency drift requirements state that the QKA855 shall not exceed a variation in frequency of .05% of Fe (or 3.275 Mc max) under the specified conditions. The thermal transient time requirements specify 1/4% of Fe (or 16.375 Mc) as the maximum allowed frequency variation from a point two minutes after application of delay line current for a period of one hour thereafter.

Four tubes were given the thermal drift and transient time tests. The first tube passed the thermal drift test but exceeded the allowed maximum frequency variation in the transient time test by .965 Mc. A minor modification was made in the coolant system which was proved-out in later tubes.

The next three tubes met the requirements of the specifications for both the frequency drift and the transient test. The thermal data for tube #14 are plotted in Figures 64 and 65. Figure 64 is a graph of the frequency transient time response in which frequency is plotted against time and shows the maximum frequency change as 2.75 Mc, whereas the allowed maximum is 3.275 Mc. Figure 65 is a graph of the thermal frequency drift performance in which frequency is plotted against oil inlet temperature and shows the maximum frequency change as 16.07 Mc, whereas the specified maximum is 16.375 Mc.

e. Life Tests

Three tubes (#11, #14 and #17) were life tested. Tube #11 ran 237 hours, when the heater opened and the test had to be discontinued. In subsequent scrap analysis, it was found that a broken weld on the heater support had caused the heater circuit to open. The broken weld was attributable to insufficient flushing of the flux material during the welding process. To prevent similar recurrences, better welding procedures were instituted and tighter controls were established.

Tube #17 ran 440 hours on life test, after which the test was discontinued and the tube was electrically tested. The electrical tests showed that the tube had not suffered any noticeable degradation in power from the prolonged testing. The electrical data comparing the performance before and after life were shown in Figure 63 in which power output (under 300 mA sole tuning conditions) was plotted against frequency.

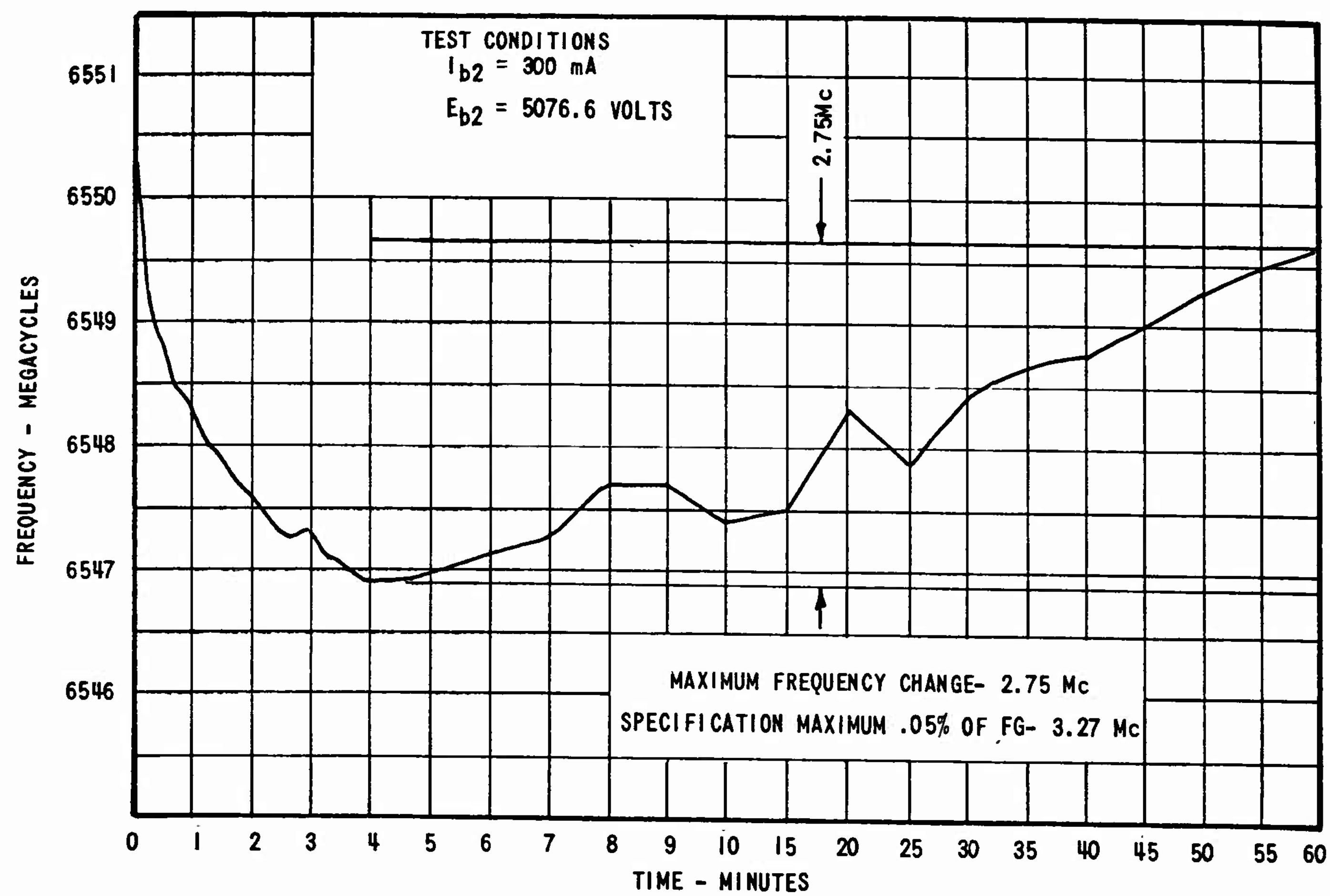
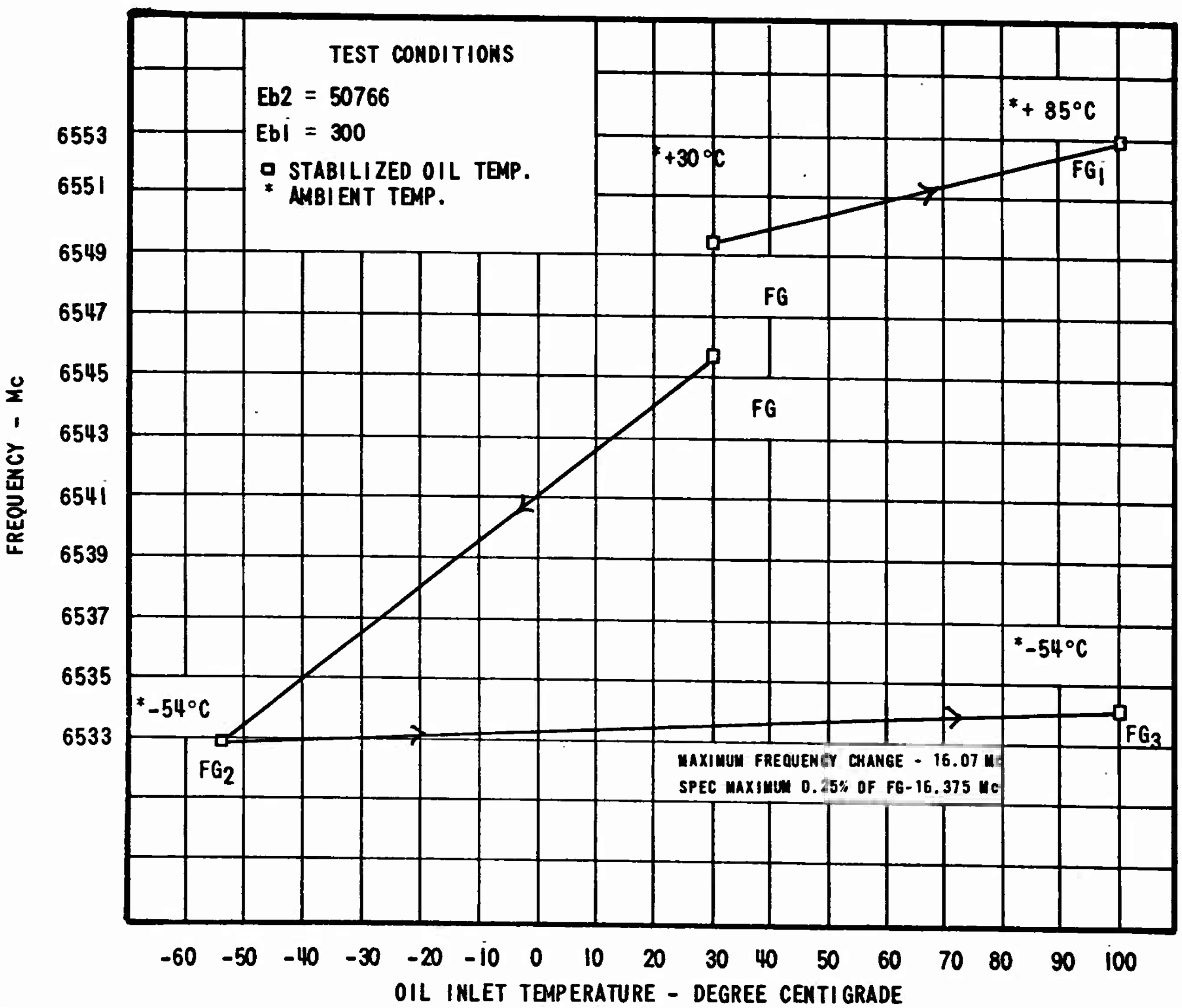


FIGURE 64 QKA 855 NO. 14 FREQUENCY TRANSIENT TIME



QKA 855 NO.14 THERMAL FREQUENCY DRIFT

FIGURE 65

Tube #14 ran on life test for 400 hours before being taken-off for evaluation.. The tube continued to operate satisfactorily in electrical tests conducted afterwards. The minimum power data for Oscillations I, II and III (I_{b2} = 300 ma) are plotted in Figure 66.

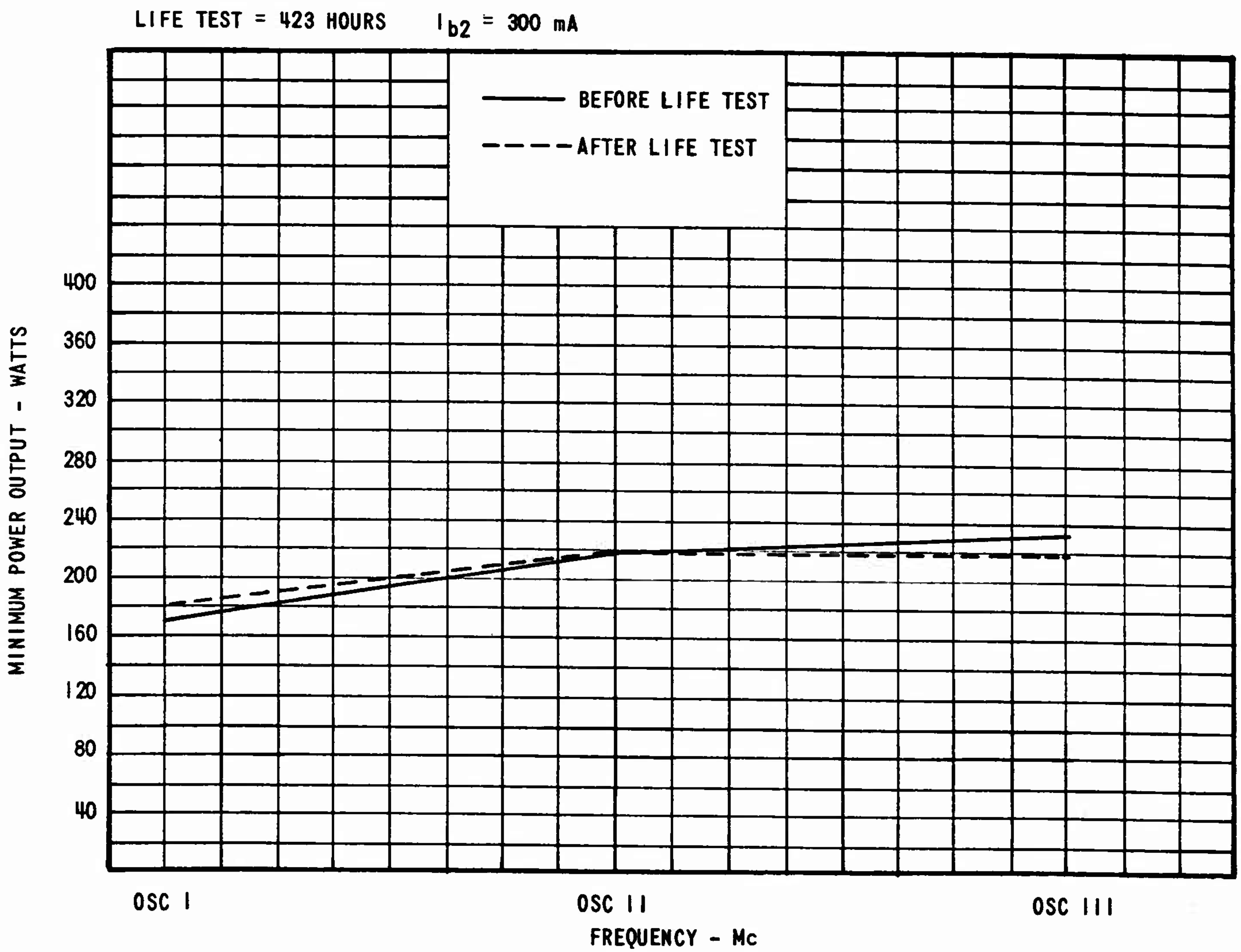


FIGURE 66 QKA 855 NO.014 MINIMUM POWER OUTPUT vs FREQUENCY IN OSC I, II, AND III BEFORE AND AFTER LIFE TEST

5 <u>QKA857</u>

a. <u>Electrical Tests</u>

During the Phase II period, initial effort was devoted principally to stabilizing the desigh with respect to the specifications. Electrical tests on QKA857 models showed that the tube meets the specification requirements. Spurious signals were reduced to well below the twenty db level, and frequency discontinuities were eliminated.

To achieve the maximum rf output, focusing parameters were adjusted with respect to delay-line dimensions to produce the most desirable beam optics. Sole-to-anode distance was varied, and an optimum position of the cathode emitting surface with respect to the varying electric field (as the tube is tuned) was established. Starting currents were lowered by increasing the number of gain sections in the delay line, and the sole end shields were extended further over the interaction space to confine the electron beam and thereby improve beam coupling and increase rf power output.

Tubes constructed during the production-fabrication phase were tested to the ASRCTE Specifications, Exhibit No. 7-65a/615a, dated 1 March 1962. Four tubes were obtained which met all of the specified requirements. Three of these were placed to one side and will be delivered to the Air Force when notice of acceptance and approval has been received. (The performance data of these tubes are given in Tables 10, 11 and 12 of the electrical data section, pages 137, 138 and 139.) Three tubes, not complying with all of the requirements, were subjected to complete environmental and life tests.

Figures 67 and 68 depict anode and sole tuning characteristics (power output vs frequency) for tube #15, which is one of the three tubes available for shipment under the Phase II requirements and which is representative of the lot. Figure 67 shows the anode tuning performance

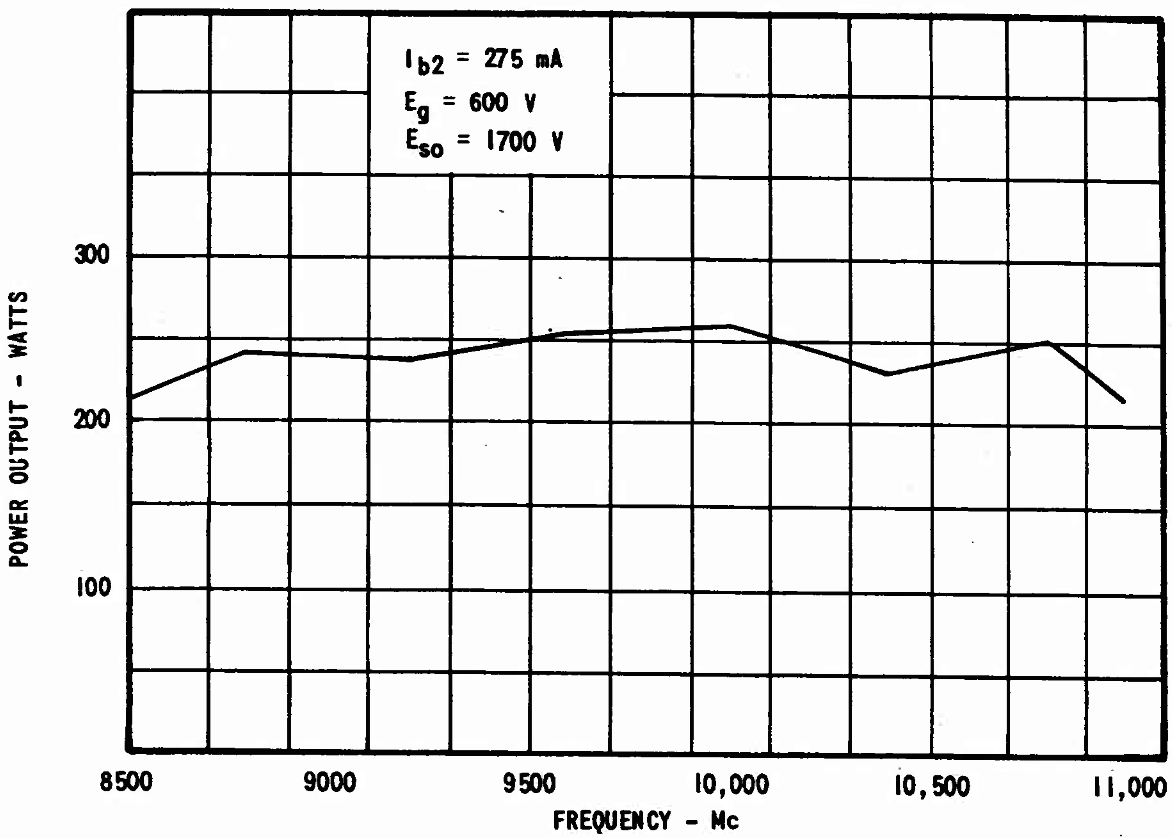


FIGURE 67

QKA 857 NO.15 ANODE TUNING CURVE
Po vs. FREQUENCY FOR OSC V

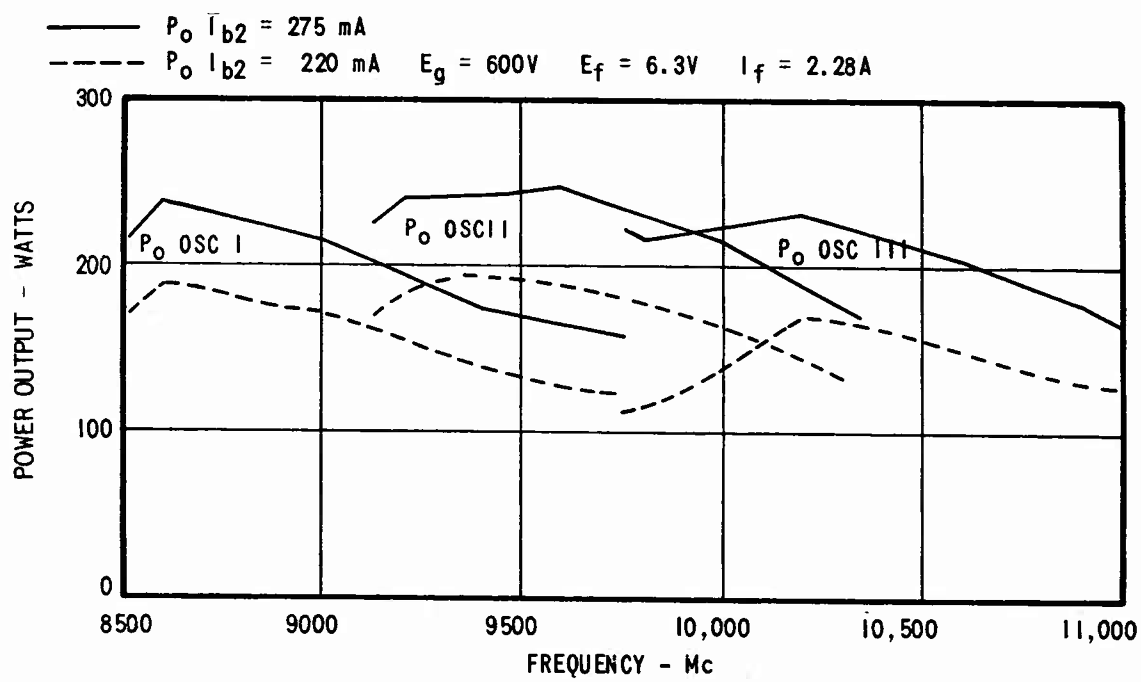


FIGURE 68 QKA 857 NO. 15 1/2 BAND SOLE TUNED

(Oscillation V) in which the minimum power obtained is 217 watts. Figure 68 represents the half band sole tuning curves showing a minimum power point of 160 watts. No observable missing frequency bands or spurious levels greater than twenty db were obtained.

b. <u>Thermal Tests</u>

For the band 8 tube, the thermal frequency drift may not exceed 27. 5 Mc at 11, 000 Mc and the thermal frequency transient may not exceed 5. 5 Mc at 11, 000 Mc.

Three tubes were subjected to the complete thermal test and all three tubes passed the requirements for thermal frequency drift and for thermal transient time.

The second tube tested, which is typical of the three tubes, had a frequency drift of 16. 22 Mc and a frequency transient of 2. 42 Mc.

c. <u>Life Tests</u>

Two QKA857 tubes were life tested. The first tube ran continuously for 537 hours before its life test was terminated by an open heater. The second tube, #15, ran more than 440 hours and continued afterwards to operate satisfactorily. The sole tuning data before and after life test for this tube are shown plotted in Figure 69.

The failure of the first tube at 537 hours was attributed to an improper cathode support weld, which was most probably weakened during the vibration tests preceeding life test. The weld on later tubes was strengthened by using a platinum sleeve about the cathode lead as a welding flux.

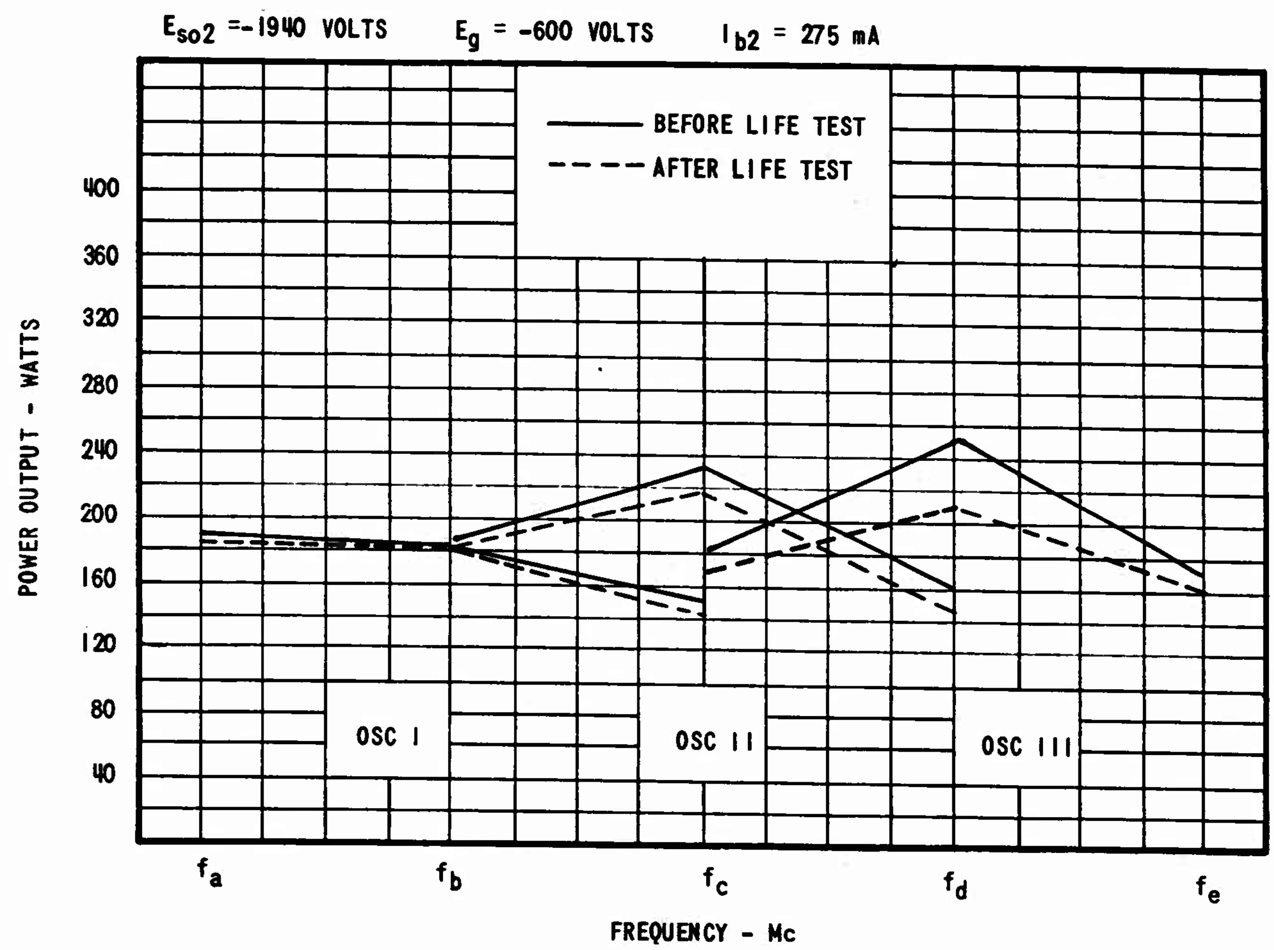


FIGURE 69 QKA 857 NO.15 SOLE TUNING PERFORMANCE BEFORE AND AFTER LIFE TEST

d. Vibration Tests

Two tubes, #4 and #17, underwent complete vibration testing and passed all the requirements of the test. The operational data before and after complete vibration tests are compared in Figures 70 and 71. No severe resonances were detected at discrete points in the vibration spectrum. In both tubes, however, there was a gradual increase in resonance as the vibration frequency approached 1500 cps in the plane of vibration perpendicular to the equatorial plane of the tube. This buildup was evidenced by a gradual buildup of noise between approximately 900 and 1500 cps at 5 "g"s. The cause of this resonance was traced directly to the magnet plate which resonates as a high frequency diaphragm.

There were no detectable modulations imposed on the rf signal as the tube was operated at fe in this vibration region. Moreover, results of electrical tests on the subject two tubes (as can be seen from the above graphs) indicated no degradation in the performance characteristics.

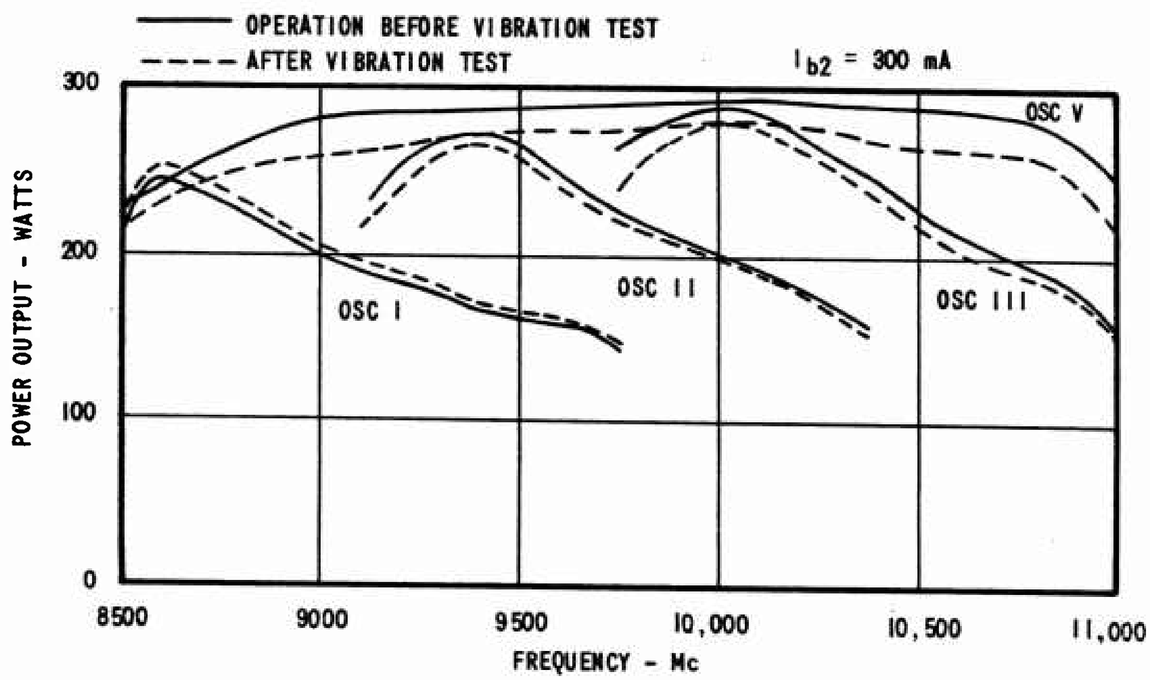


FIGURE 70

QKA 857 NO. 4 POWER OUTPUT vs. FREQUENCY

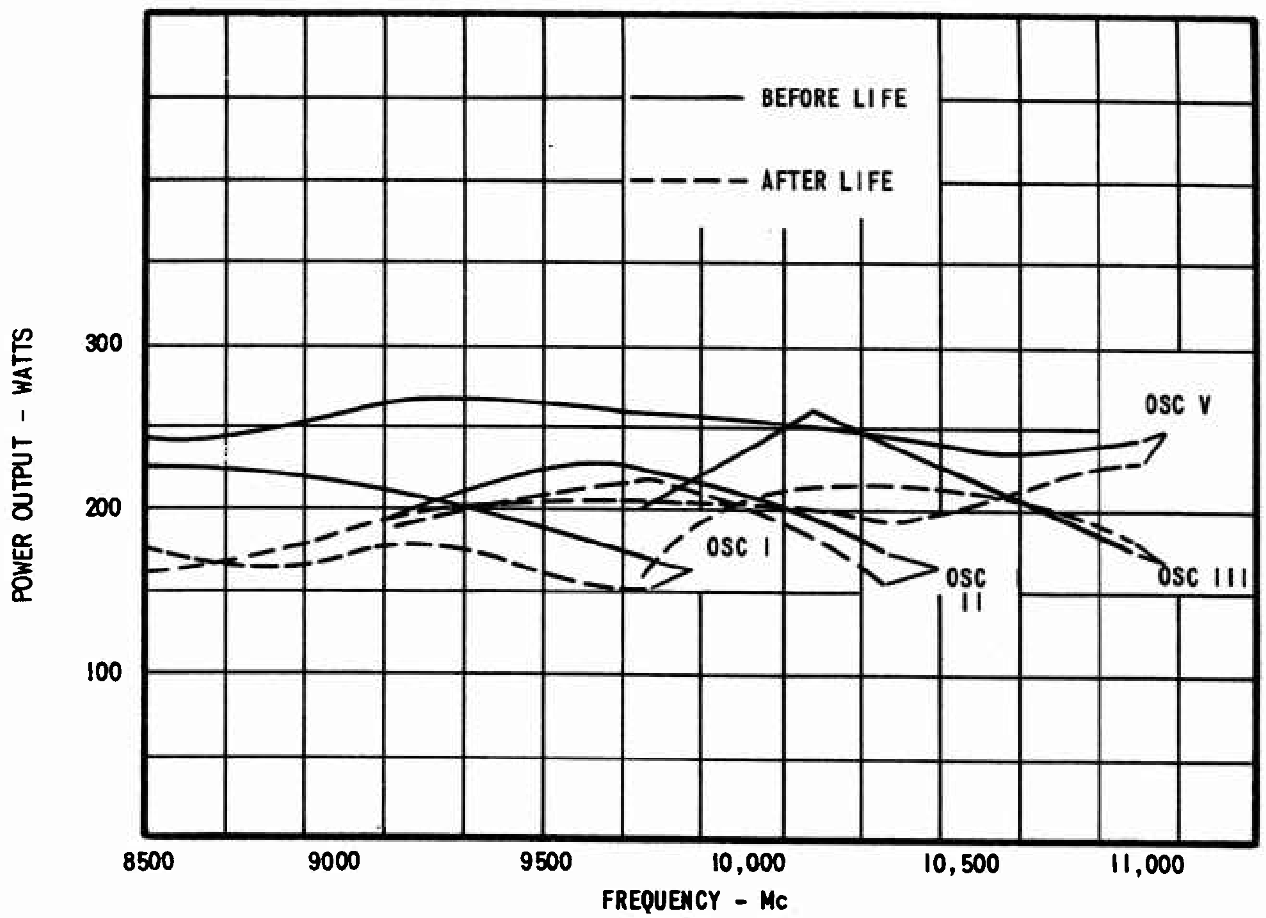


FIGURE 71 QKA 857 NO.17 OPERATION BEFORE AND AFTER COMPLETE VIBRATION TEST

POWER OUTPUT vs. FREQUENCY AT I_{b2} = 300 mA

ELECTRICAL DATA

The following tables show the electrical data taken on the three tubes of each type which have been prepared for shipment under the contract. Tables 1 through 3 list the data taken on the three Band 2 (QKA851) tubes, #10, #9 and #2. Tables 4 through 6 show the Band 3 (QKA852) data for tubes #25, #26 and #21; tables 7 through 9 show the Band 6 (QKA855) data for tubes #37, #38 and #40; tables 10 through 12 list the Band 8 (QKA857) data for tubes #13, #7 and #14.

Table 1

Dept. 3680 - CARCINOTRON
Spec. #ASRCTE 652A/695A

QKA851 #10

Test Set LTN 1685

Date 6-13-62

E_{so1} 1.40 kv
E_{so2} 1.67 kv
E_g -300 V
If 2.84 A

I_{b2} = 300 ma	-20 ma Iso max.	+5 ma Iso min	.9-1.9 kv Eacc (avg)	165W Po min.	15 db max. Spurious
Osc. I	-2	0	1.42	200	20 db
Osc. II	-4	0	1.41	251	none
Osc. III	-4.5	+.5	1.37	297	none
Osc. IV	-4.5	-.5	1.41	253	none
Osc. V	-6	-2	1.38	200	none

I_{b2} = 220ma	.8-1.9 kv Eacc	100 W Po min.
Osc. I	1.26	110
Osc. II	1.23	150
Osc. III	1.20	142

at 300 ma

Osc. I E_{b2} = 2.53 kv
Osc. II E_{b2} = 3.22 kv
Osc. III E_{b2} = 3.99 kv

Osc. I	Power 220ma	300 ma	Eso kv
1300	180	275	-1.05
1440	173	253	-1.67
1575	110	200	-2.32

Osc. IV	Power 300 ma	E_{b2} kv
1440	253	2.53
1575	310	3.22
1715	360	3.99

Frequency Pulling -25 mcs

1300 4
1575 3
1850 1

Osc. II	Power 220ma	300 ma	Eso kv
1440	204	345	-1.03
1575	175	310	-1.67
1715	150	251	-2.43

Osc. V	Power 300ma	E_{b2} kv
1300	200	2.15
1575	360	3.38
1850	330	5.13

Pressure Drop -13 lbs

ΔP30 10.5

Osc. III	Power 220ma	300 ma	Eso kv
1575	142	330	-.971
1715	180	360	-1.67
1850	172	297	-2.51

C_{so} 65.5 μf C_{acc} 17 μf Cg 20 μf

Frequency discontinuity	1.5/1 VSWR 1 mc. max.
Osc. I thru Osc. V	none

Table 2

Dept. 3680 - CARCINOTRON
Spec. #ASRCTE 652A/695A

QKA851 #9

Test Set LTN 2311

Date 12-8-62

E_{sol} 1.40 kv
E_{so2} 1.67 kv
E_g -200 V
I_f 2.8 A

I_{b2} =325 ma	-20 ma Iso max.	+5 ma Iso min	.9-1.9 kv Eacc (avg)	165W Po min.	15 db max. Spurious
Osc. I	- 5	0	1.39	240	20 db
Osc. II	- 5	0	1.35	279	17 db
Osc. III	-12.5	0	1.32	314	none
Osc. IV	- 5	- 2	1.35	306	none
Osc. V	- 2	-16	1.34	279	none

I_{b2} = 220ma	.8-1.9 kv Eacc	100 W Po min.
Osc. I	1.19	125
Osc. II	1.16	146
Osc. III	1.13	167

at 300 ma

Osc. I E_{b2} = 2.51 kv

Osc. II E_{b2} = 3.23 kv

Osc. III E_{b2} = 3.97 kv

Osc. I	Power 220ma	Power 325 ma	Eso kv
1300	215	292	-1.01
1440	188	306	-1.67
1575	125	240	-2.34

Osc. IV	Power 325 ma	E_{b2} kv
1440	306	2.51
1575	376	3.23
1715	418	3.97

Frequency Pulling -25 mcs

1300 4

1575 3

1850 1

Osc. II	Power 220ma	Power 325 ma	Eso kv
1440	209	362	- .975
1575	198	376	-1.67
1715	146	279	-2.45

Osc. V	Power 325 ma	E_{b2} kv
1300	279	2.11
1575	418	3.50
1850	438	5.06

Pressure Drop -13 lbs

ΔP30 10.5

Osc. III	Power 220ma	Power 325 ma	Eso kv
1575	167	390	- .930
1715	202	418	-1.67
1850	167	314	-2.52

C_{so} 62.8 µf C_{acc} 16.8 µf Cg 20 µf

Frequency discontinuity	1.5/1 VSWR 1 mc. max.
Osc. I thru Osc. V	none

Table 3

Dept. 3680 - CARCINOTRON
Spec. #ASRCTE 652A/695A

QKA851 #002

Test Set LTN 1703

Date 7-30-62

E_{so1} -1.40 kv
E_{so2} -1.70 kv
E_g -200 V
I_f 2.67 A

I_{b2} =300 ma	-20 ma Iso max.	+5 ma Iso min	.9-1.9 kv Eacc (avg)	165W Po min.	15 db max. Spurious
Osc. I	-2	+1	1.33	210	15 db
Osc. II	-4	+2	1.30	238	none
Osc. III	-2	0	1.26	210	none
Osc. IV	0	0	1.27	328	none
Osc. V	-7	0	1.27	285	none

I_{b2} = 220ma	.8-1.9 kv Eacc	100 W Po min.
Osc. I	1.15	109
Osc. II	1.13	115
Osc. III	1.10	140

at 300 ma

Osc. I E_{b2} = 2.46 kv

Osc. II E_{b2} = 3.18 kv

Osc. III E_{b2} = 3.96 kv

Osc. I	Power 220ma	Power 300 ma	Eso kv
1300	157	325	-1.06
1440	170	290	-1.70
1575	109	210	-2.39

Osc. IV	Power 300 ma	E_{b2} kv
1440	290	2.46
1575	346	3.16
1715	368	3.96

Frequency Pulling -25 mcs

1800 4

1575 4.5

1850 4

Osc. II	Power 220ma	Power 300 ma	Eso kv
1440	177	255	-1.01
1575	176	346	-1.70
1715	115	238	-2.50

Osc. V	Power 300 ma	E_{b2} kv
1300	285	2.29
1575	361	3.46
1850	320	5.00

Pressure Drop -13 lbs

ΔP30 11

Osc. III	Power 220ma	Power 300 ma	Eso kv
1575	142	215	- .960
1715	157	368	-1.70
1850	140	210	-2.55

C_{so} 62.8 µf C_{acc} 16.8 µf Cg 20.1 µf

Frequency discontinuity	1.5/1 VSWR 1 mc. max.
Osc. I thru Osc. V	none

Table 4

Dept. 3680 - CARCINOTRON
Spec. #ASRCTE 652A/695A
QKA852 #25

Test Set LTN 1685

Date 8-6-62

E_{sol} -1.40 kv
E_{so2} -1.75 kv
E_g -300 V
I_f 2.5 A

I_{b2} = 325 ma	-20 ma Iso max.	+5 ma Iso min	.9-1.9 kv Eacc (avg)	165W Po min.	15 db max. Spurious
Osc. I	-4	+.5	1.28	210	none
Osc. II	-6	+1	1.27	250	none
Osc. III	-8	+2	1.26	250	none
Osc. IV	-3.5	-1.5	1.27	225	none
Osc. V	-9.5	-3.5	1.27	200	none

I_{b2} = 220ma	.8-1.9 kv Eacc	100 W Po min.
Osc. I	1.10	126
Osc. II	1.10	132
Osc. III	1.10	112

at 300 ma

Osc. I E_{b2} = 2.58 kv
Osc. II E_{b2} = 3.23 kv
Osc. III E_{b2} = 3.94 kv

Osc. I	Power 220ma	Power 325 ma	Eso kv
1800	126	250	-1.21
1990	158	225	-1.75
2175	138	210	-2.38

Osc. IV	Power 325 ma	E_{b2} kv
1990	225	2.58
2175	317	3.23
2365	355	3.94

Frequency Pulling -25 mcs

1800	1.8
2175	2.8
2550	3.5

Osc. II	Power 220ma	Power 325 ma	Eso kv
1990	132	250	-1.17
2175	170	317	-1.75
2365	171	265	-2.46

Osc. V	Power 325 ma	E_{b2} kv
1800	200	2.29
2175	330	3.56
2550	335	5.06

Pressure Drop -13 lbs

ΔP30 10.5

Osc. III	Power 220ma	Power 325 ma	Eso kv
2175	112	250	-1.10
2365	198	255	-1.75
2550	200	315	-2.53

C_{so} 68.8 μf C_{acc} 17.6 μf Cg 19.8 μf

Frequency discontinuity	1.5/1 VSWR 1 mc. max.
Osc. I thru Osc. V	none

Table 5

Dept. 3680 - CARCINOTRON
Spec. #ASRCTE 652A/695A

QKA852 #26

Test Set LTN 1685

Date 8-14-62

E_{so1} 1.42 kv
E_{so2} 1.80 kv
E_g -400 V
I_f 2.54 A

I_{b2} = 300 ma	-20 ma Iso max.	+5 ma Iso min	.9-1.9 kv Eacc (avg)	165W Po min.	15 db max. Spurious
Osc. I	-1	+.5	1.26	210	none
Osc. II	-1.5	0	1.26	255	none
Osc. III	-2.5	0	1.25	307	none
Osc. IV	-2	0	1.26	237	none
Osc. V	-6	-.5	1.25	261	

I_{b2} = 220ma	.8-1.9 kv Eacc	100 W Po min.
Osc. I	1.10	125
Osc. II	1.10	149
Osc. III	1.10	107

at 300 ma

Osc. I E_{b2} = 2.56 kv
Osc. II E_{b2} = 3.23 kv
Osc. III E_{b2} = 3.95 kv

Osc. I	Power 220ma	Power 300 ma	Eso kv
1800	160	262	-1.19
1990	143	237	-1.80
2175	125	210	-2.41

Osc. IV	Power 300 ma	E_{b2} kv
1990	237	2.56
2175	297	3.23
2365	330	3.95

Frequency Pulling -25 mcs

1800 0
2175 1.5
2550 2.5

Osc. II	Power 220ma	Power 300 ma	Eso kv
1990	149	333	-1.17
2175	170	297	-1.80
2365	147	255	-2.48

Osc. V	Power 300 ma	E_{b2} kv
1800	261	2.36
2175	340	3.68
2550	385	5.18

Pressure Drop -13 lbs

ΔP30 11

Osc. III	Power 220ma	Power 300 ma	Eso kv
2175	107	318	-1.12
2365	198	330	-1.80
2550	176	307	-2.54

C_{so} 68.2 µf C_{acc} 17.2 µf Cg 19.8 µf

Frequency discontinuity	1.5/1 VSWR 1 mc. max.
Osc. I thru Osc. V	none

Table 6

Dept. 3680 - CARCINOTRON
Spec. #ASRCTE 652A/695A

QKA852 #21

Test Set LTN 1703

Date ____________

E_{so1} -1.55 kv
E_{so2} -1.98 kv
E_g - 500 V
I_f 2.8 A

I_{b2} = 325 ma	-20 ma Iso max.	+5 ma Iso min	.9-1.9 kv Eacc (avg)	165W Po min.	15 db max. Spurious
Osc. I	0	+1.0	1.29	200	none
Osc. II	0	+1.0	1.29	250	none
Osc. III	-3	+1.0	1.27	283	none
Osc. IV	0	+1.0	1.29	237	none
Osc. V	-5	0	1.27	241	none

I_{b2} = 220ma	.8-1.9 kv Eacc	100 W Po min.
Osc. I	1.11	110
Osc. II	1.09	125
Osc. III	1.10	106

at 300 ma

Osc. I E_{b2} = 2.48 kv
Osc. II E_{b2} = 3.17 kv
Osc. III E_{b2} = 3.95 kv

Osc. I	Power 220ma	Power 325 ma	Eso kv
1800	152	270	-1.35
1990	143	237	-1.98
2175	110	200	-2.60

Osc. IV	Power 325 ma	E_{b2} kv
1990	237	2.48
2175	304	3.17
2365	342	3.95

Frequency Pulling
-25 mcs

1800 4.0
2175 2.0
2550 5.0

Osc. II	Power 220ma	Power 325 ma	Eso kv
1990	133	286	-1.35
2175	150	304	-1.98
2365	125	250	-2.70

Osc. V	Power 325 ma	E_{b2} kv
1800	241	2.36
2175	334	3.65
2550	375	5.20

Pressure Drop
-13 lbs

ΔP30 10.5

Osc. III	Power 220ma	Power 325 ma	Eso kv
2175	106	283	-1.26
2365	172	342	-1.98
2550	167	310	-2.76

C_{so} 67.5 µf C_{acc} 17.1 µf Cg 20.0 µf

Frequency discontinuity	1.5/1 VSWR 1 mc. max.
Osc. I thru Osc. V	none

Table 7

Dept. 3680 - CARCINOTRON
Spec. #ASRCTE 652A/695A

QKA855 #38

Test Set LTN 2000

Date 1-29-63

E_{so1} 1.651 kv
E_{so2} -1.92 kv
E_g - 300 V
I_f 2.7 A

I_{b2} = 300 ma	-20 ma Iso max.	+5 ma Iso min	.9-1.9 kv Eacc (avg)	165W Po min.	15 db max. Spurious
Osc. I	-.5	0	1.300	170	none
Osc. II	0	0	1.290	185	22.0
Osc. III	-.5	+.5	1.280	214	none
Osc. IV	-.5	+.5	1.290	235	18.0
Osc. V	-1.0	0	1.270	166	none

I_{b2} = 220ma	.8-1.9 kv Eacc	100 W Po min.
Osc. I	1.155	115
Osc. II	1.145	126
Osc. III	1.140	105

at 300 ma

Osc. I E_{b2} = 2.58 kv
Osc. II E_{b2} = 3.20 kv
Osc. III E_{b2} = 3.94 kv

Osc. I	Power 220ma	Power 300 ma	Eso kv
4800	115	189	-1.340
5235	138	230	-1.930
5675	123	185	-2.550

Osc. IV	Power 300 ma	E_{b2} kv
5235	230	-2.58
5625	256	3.20
6115	235	3.94

Frequency Pulling -25 mcs

4800 6
5675 6
6550 1

Osc. II	Power 220ma	Power 300 ma	Eso kv
5235	126	209	-1.310
5675	158	256	-1.930
6115	128	199	-2.600

Osc. V	Power 300 ma	E_{b2} kv
4800	166	2.300
5675	217	3.539
6550	197	5.100

Pressure Drop -13 lbs

ΔP30 10.0

Osc. III	Power 220ma	Power 300 ma	Eso kv
5675	105	238	-1.310
6115	153	230	-1.930
6550	140	209	-2.690

C_{so} 54.5 µf C_{acc} 12.1 µf Cg 16.8 µf

Frequency discontinuity	1.5/1 VSWR 1 mc. max.
Osc. I thru Osc. V	none

Table 8

Dept. 3680 - CARCINOTRON
Spec. #ASRCTE 652A/695A

QKA855 #37

Test Set LTN 1685

Date 1-28-63

E_{so1} -1.70 kv
E_{so2} -1.96 kv
E_g - 400 V
If 2.73 A

I_{b2} =300 ma	-20 ma Iso max.	+5 ma Iso min	.9-1.9 kv Eacc (avg)	165W Po min.	15 db max. Spurious
Osc. I	0	0	1.34	200	20 db
Osc. II	0	+.5	1.34	200	18 db
Osc. III	0	+.5	1.33	232	none
Osc. IV	0	+.5	1.33	228	18 db
Osc. V	0	+.5	1.31	213	18 db

I_{b2} = 220ma	.8-1.9 kv Eacc	100 W Po min.
Osc. I	1.21	123
Osc. II	1.21	135
Osc. III	1.19	143

at 300 ma

Osc. I E_{b2} = 2.60 kv

Osc. II E_{b2} = 3.26 kv

Osc. III E_{b2} = 4.00 kv

Osc. I	Power 220ma	Power 300 ma	Eso kv
4800	123	220	-1.36
5235	148	228	-1.96
5675	132	200	-2.59

Osc. IV	Power 300 ma	E_{b2} kv
5235	228	2.60
5625	261	3.26
6115	290	4.00

Frequency Pulling -25 mcs

4800 4.0
5675 3.0
6550 1.5

Osc. II	Power 220ma	Power 300 ma	Eso kv
5235	135	200	-1.30
5675	174	261	-1.96
6115	155	229	-2.68

Osc. V	Power 300 ma	E_{b2} kv
4800	213	2.32
5675	262	3.53
6550	261	5.11

Pressure Drop -13 lbs

ΔP30 10.5

Osc. III	Power 220ma	Power 300 ma	Eso kv
5675	143	232	-1.26
6115	190	290	-1.96
6550	155	236	-2.74

C_{so} 60 µf C_{acc} 12.5 µf Cg 18.1 µf

Frequency discontinuity	1.5/1 VSWR 1 mc. max.
Osc. I thru Osc. V	none

Table 9

Dept. 3680 - CARCINOTRON
Spec. #ASRCTE 652A/695A

QKA855 #40

Test Set LTN ____

Date 1-29-63

E_{so1} -1.68 kv
E_{so2} -1.84 kv
E_g - 500 V
I_f 2.85 A

I_{b2} = 300ma	-20 ma Iso max.	+5 ma Iso min	.9-1.9 kv Eacc (avg)	165W Po min.	15 db max. Spurious
Osc. I	-1	0	1.38	180	none
Osc. II	-2	0	1.38	200	none
Osc. III	-3	0	1.38	202	none
Osc. IV	-2	0	1.38	210	none
Osc. V	-4	0	1.38	170	none

I_{b2} = 220ma	.8-1.9 kv Eacc	100 W Po min.
Osc. I	1.240	131
Osc. II	1.240	142
Osc. III	1.235	143

at 300 ma

Osc. I E_{b2} = 2.60 kv

Osc. II E_{b2} = 3.28 kv

Osc. III E_{b2} = 3.98 kv

Osc. I	Power 220ma	Power 300 ma	Eso kv
4800	162	231	-1.30
5235	142	210	-1.84
5675	131	181	-2.48

Osc. IV	Power 300 ma	E_{b2} kv
5235	208	2.60
5675	267	3.28
6115	250	3.98

Frequency Pulling -25 mcs

4800 6

5675 9

6550 3

Osc. II	Power 220ma	Power 300 ma	Eso kv
5235	1600	294	-1.20
5675	177	268	-1.84
6115	142	193	-2.50

Osc. V	Power 300 ma	E_{b2} kv
4800	170	2.20
5675	290	3.46
6550	226	4.95

Pressure Drop -13 lbs

ΔP30 10.2

Osc. III	Power 220ma	Power 300 ma	Eso kv
5675	176	340	-1.16
6115	165	256	-1.84
6550	142	200	-2.59

C_{so} 54.5 μf C_{acc} 12.3 μf Cg 18.3 μf

Frequency discontinuity	1.5/1 VSWR 1 mc. max.
Osc. I thru Osc. V	none

Table 10

Dept. 3680 - CARCINOTRON
Spec. #ASRCTE 652A/695A

QKA857 #13

Test Set LTN 1688

Date 8-28-62

E_{so1} -1.70 kv
E_{so2} -2.05 kv
E_g - 600 V
I_f 2.28 A

I_{b2} = 300ma	-20 ma Iso max.	+5 ma Iso min	.9-1.9 kv Eacc (avg)	165W Po min.	15 db max. Spurious
Osc. I	-2.0	-.5	1.34	173	none
Osc. II	-4.0	-1.0	1.28	181	none
Osc. III	-7.0	-1.0	1.20	188	none
Osc. IV	-2.0	-1.0	1.28	216	none
Osc. V	-7.5	-.5	1.33	228	none

I_{b2} = 220ma	.8-1.9 kv Eacc	100 W Po min.
Osc. I	1.157	123
Osc. II	1.108	132
Osc. III	1.017	111

at 300 ma

Osc. I E_{b2} = 2.60 kv

Osc. II E_{b2} = 3.18 kv

Osc. III E_{b2} = 3.84 kv

Osc. I	Power 220ma	300 ma	Eso kv
8500	166	245	-1.54
9125	150	200	-2.03
9750	123	173	-2.62

Osc. IV	Power 300 ma	E_{b2} kv
9125	200	2.60
9750	245	3.15
10,375	260	3.84

Frequency Pulling -25 mcs

4800	4
5675	2
6550	1

Osc. II	Power 220ma	300 ma	Eso kv
9125	167	254	-1.50
9750	180	245	-2.10
10,375	132	181	2.68

Osc. V	Power 300 ma	E_{b2} kv
8500	228	2.47
9750	255	3.52
11,000	262	4.90

Pressure Drop -13 lbs

ΔP30 10

Osc. III	Power 220ma	300 ma	Eso kv
9750	111	254	-1.43
10,375	165	260	-2.07
11,000	128	188	-2.74

C_{so} 48.5 µf C_{acc} 11.6 µf Cg 18 µf

Frequency discontinuity	1.5/1 VSWR 1 mc. max.
Osc. I thru Osc. V	none

Table 11

Dept. 3680 - CARCINOTRON
Spec. #ASRCTE 652A/695A

QKA857 #7

Test Set LTN 1688

Date 9-7-62

E_{sol} -1.55 kv
E_{so2} -1.94 kv
E_g - 600 V
I_f 2.3 A

I_{b2} = 300 ma	-20 ma Iso max.	+5 ma Iso min	.9-1.9 kv Eacc (avg)	165W Po min.	15 db max. Spurious
Osc. I	0	0	1.20	175	none
Osc. II	-1.0	0	1.12	166	none
Osc. III	-4.0	0	1.05	210	none
Osc. IV	-4	.1	1.12	231	none
Osc. V	-11	.1	1.12	206	21 db

I_{b2} = 220ma	.8-1.9 kv Eacc	100 W Po min.
Osc. I	1.037	129
Osc. II	.946	124
Osc. III	.846	102

at 300 ma

Osc. I E_{b2} = 2.60 kv
Osc. II E_{b2} = 3.19 kv
Osc. III E_{b2} = 3.81 kv

Osc. I	Power 220ma	300 ma	Eso kv
8500	150	221	-1.41
9125	170	230	-2.00
9750	129	175	-2.47

Osc. IV	Power 300 ma	E_{b2} kv
9125	230	2.60
9750	260	3.15
10,375	260	3.81

Frequency Pulling -25 mcs

4800 4
5675 2
6550 1

Osc. II	Power 220ma	300 ma	Eso kv
9125	138	222	-1.37
9750	185	260	-2.07
10,375	124	166	-2.53

Osc. V	Power 300 ma	E_{b2} kv
8500	206	2.47
9750	290	3.60
11,000	334	4.91

Pressure Drop -13 lbs

ΔP30 10

Osc. III	Power 220ma	300 ma	Eso kv
9750	102	240	-1.32
10,375	160	260	-1.86
11,000	150	210	-2.58

C_{so} 48 μf C_{acc} 11 μf Cg 18 μf

Frequency discontinuity	1.5/1 VSWR 1 mc. max.
Osc. I thru Osc. V	none

Table 12

Dept. 3680 - CARCINOTRON
Spec. #ASRCTE 652A/695A
QKA857 #14

Test Set LTN 1688

Date 8-30-62

E_{so1} 1.600 kv
E_{so2} 2.020 kv
E_g - 600 V
I_f 2.25 A

I_{b2} = ma	-20 ma Iso max.	+5 ma Iso min	.9-1.9 kv Eacc (avg)	165W Po min.	15 db max. Spurious
Osc. I	-1.0	- .5	1.233	164	none
Osc. II	-4.0	-2.0	1.217	182	none
Osc. III	-5.0	-1.0	1.272	167	none
Osc. IV	-5.0	-1.0	1.217	180	none
Osc. V	-5.0	- .5	1.217	240	none

I_{b2} = 220ma	.8-1.9 kv Eacc	100 W Po min.
Osc. I	1.074	122
Osc. II	1.061	123
Osc. III	1.016	108

at 300 ma

Osc. I E_{b2} = 2.60 kv
Osc. II E_{b2} = 3.23 kv
Osc. III E_{b2} = 3.85 kv

Osc. I	Power 220ma	300 ma	Eso kv
8500	170	228	-1.51
9125	160	180	-2.03
9750	122	164	-2.60

Osc. IV	Power 300 ma	E_{b2} kv
9125	180	2.60
9750	240	3.23
10,375	225	3.85

Frequency Pulling -25 mcs

4800 3
5675 1
6550 1

Osc. II	Power 220ma	300 ma	Eso kv
9125	152	240	-1.46
9750	185	240	-2.00
10,375	123	182	-2.68

Osc. V	Power 300 ma	E_{b2} kv
8500	240	2.54
8750	310	3.56
11,000	240	5.02

Pressure Drop -13 lbs

ΔP30 10

Osc. III	Power 220ma	300 ma	Eso kv
9750	108	270	-1.40
10,375	190	225	-1.96
11,000	117	167	-2.71

C_{so} 48 µf C_{acc} 11 µf Cg 18 µf

Frequency discontinuity	1.5/1 VSWR 1 mc. max.
Osc. I thru Osc. V	none

LIFE TEST SUMMARY ASD PROJECT 7-965

Tube Type	Tube #	Total Oscillation Time (Hours)	Status at Completion of Life Test	Remarks
QKA851	#3	1100	Met Life Test Limits	
	#4	400	Met Life Test Limits	
	#12	400	Met Life Test Limits	
QKA852	#12	856	Faulty Coolant Circulator Caused Failure at 856 Hours	Met Life Test Limits at 400 Hours
QKA855	#11	237	Open Heater Support Weld Caused Failure at 237 Hours	Met Life Test Limits at 200 Hours
	#14	400	Met Life Test Limits	
	#17	440	Met Life Test Limits	
QKA857	#4	537	Open Heater Support Weld Caused Failure at 537 Hours	Met Life Test Limits at 400 Hours
	#15	440	Met Life Test Limits	

MANUFACTURING METHODS AND PROCESSES

The many manufacturing methods and process improvements initiated during Phase I of the program were utilized in the Phase II production fabrication and evaluation effort.

A detailed presentation of specific assembly procedures is out of the scope of this report; however, the process flow of assembly operations required to manufacture QKA851, QKA852, QKA855 and QKA857 tubes is shown in Appendix I of this report.

1. Facilities

Figures 72 and 73 are photographs showing portions of the climatized assembly area in which the principal portions of the tubes were assembled. The climatized areas are maintained at a temperature of $72^{\circ}F \pm 2^{\circ}F$. Relative humidity is controlled at $40\% \pm 5\%$. Frequent dust samples taken in these areas show a concentration of airborne foreign matter which is one-tenth of that found in the main airconditioned assembly area. The following tube assembly operations were required to be conducted in the climatized area:

1. All electron gun fabrication,
2. All delay line assembly, alignment and cold test operations, and
3. All final tube assembly.

The tubes assembled under low humidity and low dust count condition were found to have a minimum of exhaust processing problems and achieved excellent pinch-off pressures.

The impregnated type cathode used in all tubes of this program is hygroscopic and easily poisoned by water vapor. Special vacuum storage containers were employed to protect all in-process cathodes and cathode assemblies between operations.

The principle facilities used to construct the tubes are listed in Figure 74.

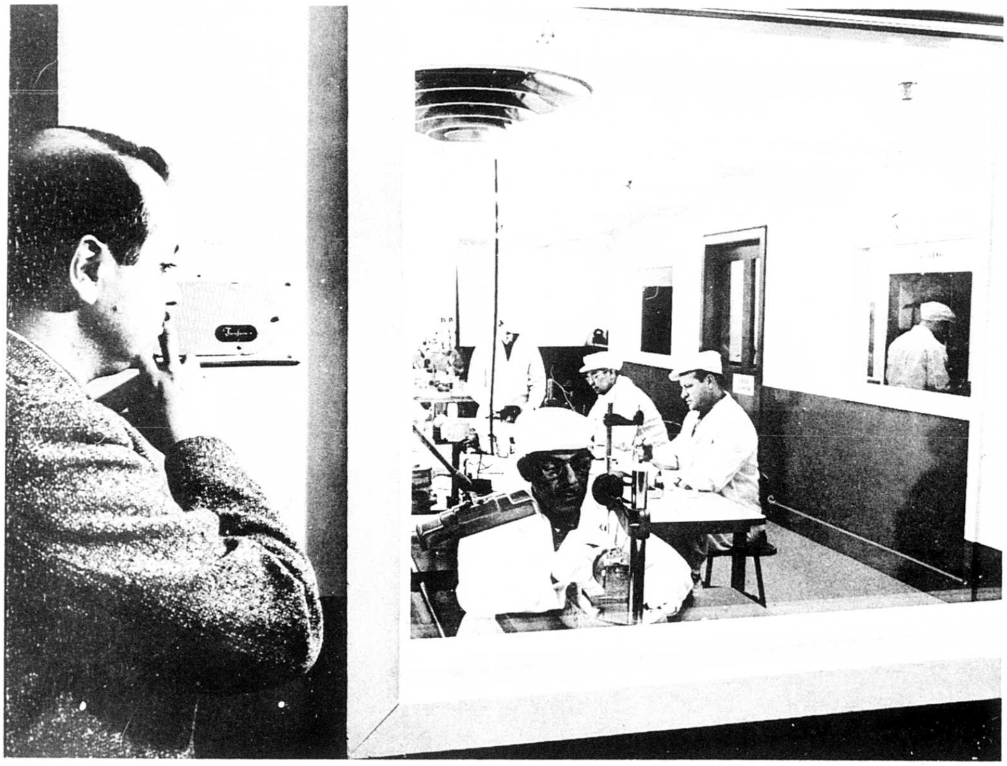
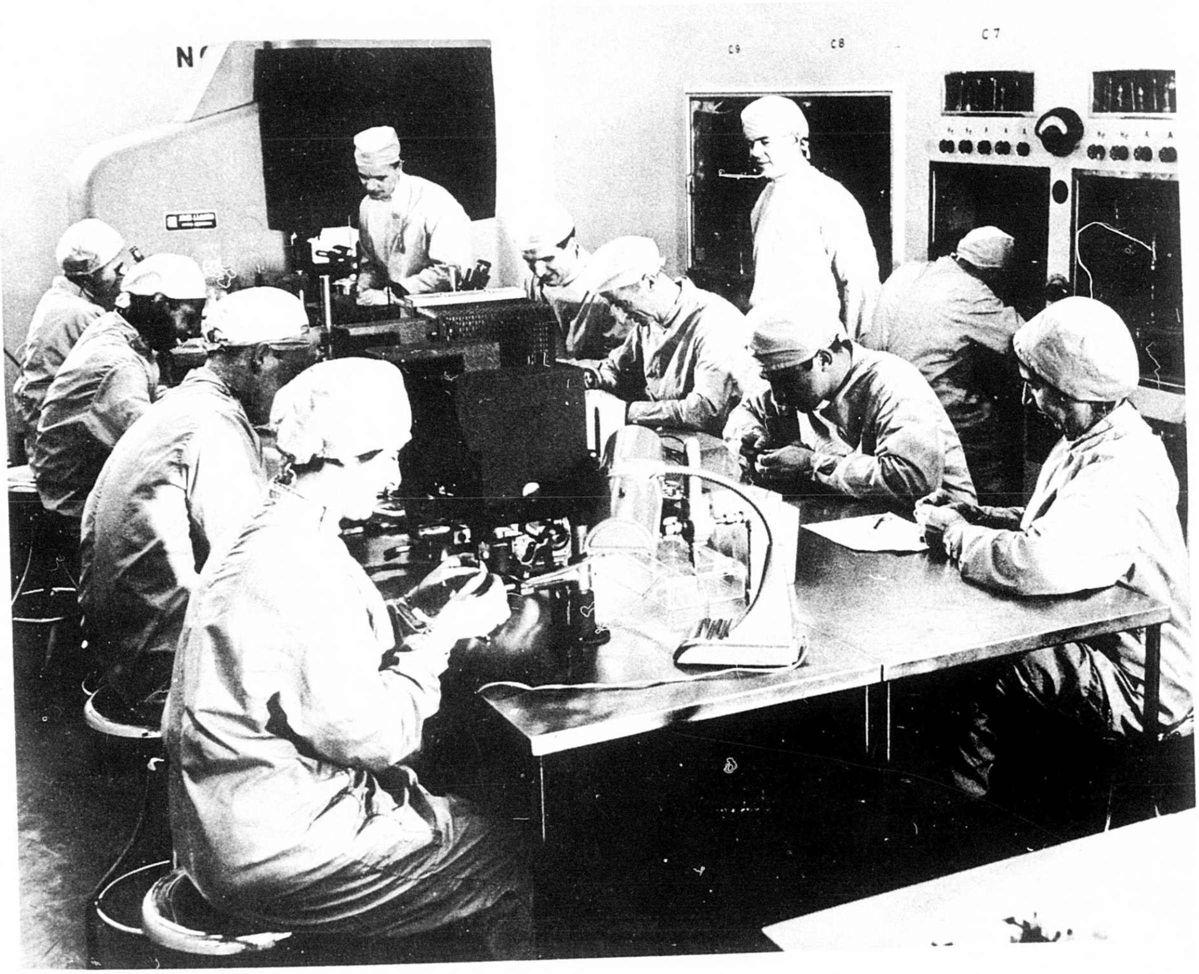


FIGURE 72 CLIMATIZED ASSEMBLY AREA



Climatized Assembly Areas

Over 4800 square feet of Spencer Laboratory is occupied by completely equipped climatized assembly areas. In these pressurized rooms, temperature and humidity are held constant and air filters minimize dust. "Air Locks" are provided for personnel to clean their hands, faces, shoes, cuffs, and to put on the special lintless smocks, caps, and gloves before entering. These measures are essential for the manufacture of high reliability, long-life, and low-noise tubes.

Figure 73

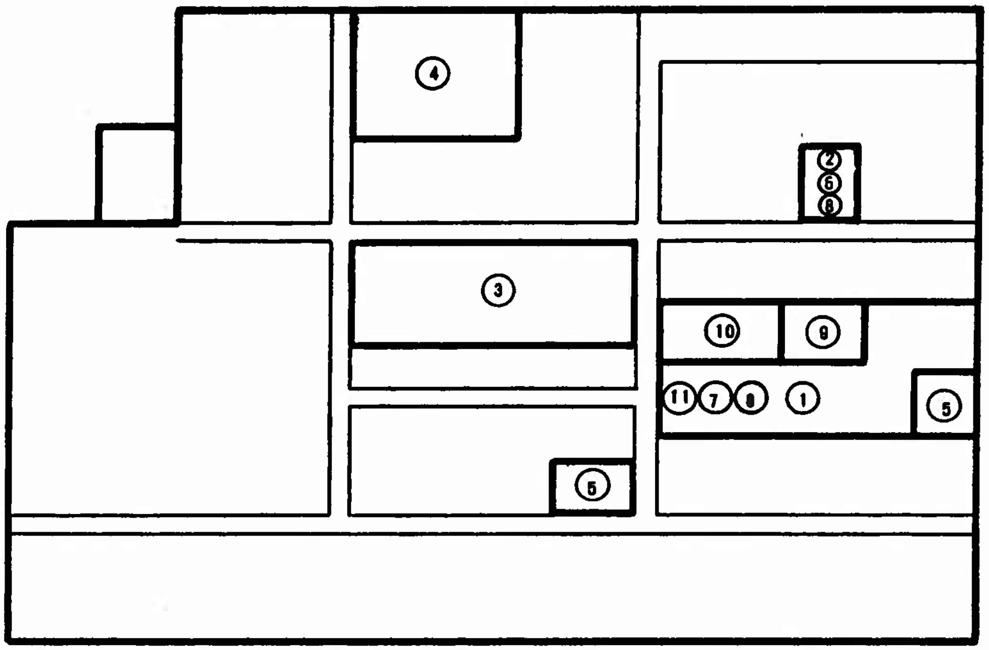


FIGURE 74 LAYOUT OF PRINCIPAL FACILITIES

Principal Facilities:

1. Assembly Area
2. Climatized Assembly Area
3. Chemical Cleaning and Degreasing
4. Cold Test
5. Inspection
6. Optical Comparator
7. Leak Detectors
8. Resistance Welders
9. Heliarc Welders (Miller)
10. Induction Heaters
11. Packaging

Support Facilities also Required but not Shown:

1. Cathode Fabrication
2. Ceramics
3. Plating
4. Furnaces (Belt, Block and Vacuum)
5. X-Ray
6. Sandblasting
7. Machine Shop

2. Prime Parts Manufacturing Methods

a. Crowns

The QKA852, QKA855 and QKA857 tubes employ crowns to form the delay line or slow-wave structure. The assembled delay line is the most expensive item required in the construction of the above tube types. Crown manufacturing methods, therefore, were subjected to an extensive analysis and refinement.

All crowns were designed to be manufactured by the hobbing technique. This method allows the use of copper for construction of M-type backward-wave oscillator delay lines with its high electrical and thermal conductivity. The hobbing method, which actually cold works the copper, eases the handling problem during the construction and inspection of the tube because of the resulting hardness of the interdigital fingers. The hobbing method is well suited to production.

Crowns for the higher frequency tubes, namely the QKA855 and QKA857, received the most attention since the need for stringent finger alignment and close dimensional accuracy increases rapidly with frequency, with the result that crown costs are significantly higher at frequencies above "S" band.

Efforts to improve the method of crown manufacture were directed toward 1) increasing the accuracy of the hob, 2) improving machining methods and techniques, and 3) refining inspection procedures and facilities.

Hob grinding methods were upgraded, and a system for controlling coolant and ambient temperature was instituted during the course of the program. The extreme accuracy which was achieved is shown in Figure 75 which depicts the finger-to-finger spacing of a QKA857 hobbed crown. An improved hob inspection procedure which utilized an optical dividing head was employed to establish the accuracy of hobs. The optical dividing head is accurate to ± 1 second of arc, which permits measurements with a limit of accuracy of better than $\pm .00005$ inch at diameters equivalent to the QKA857 hob.

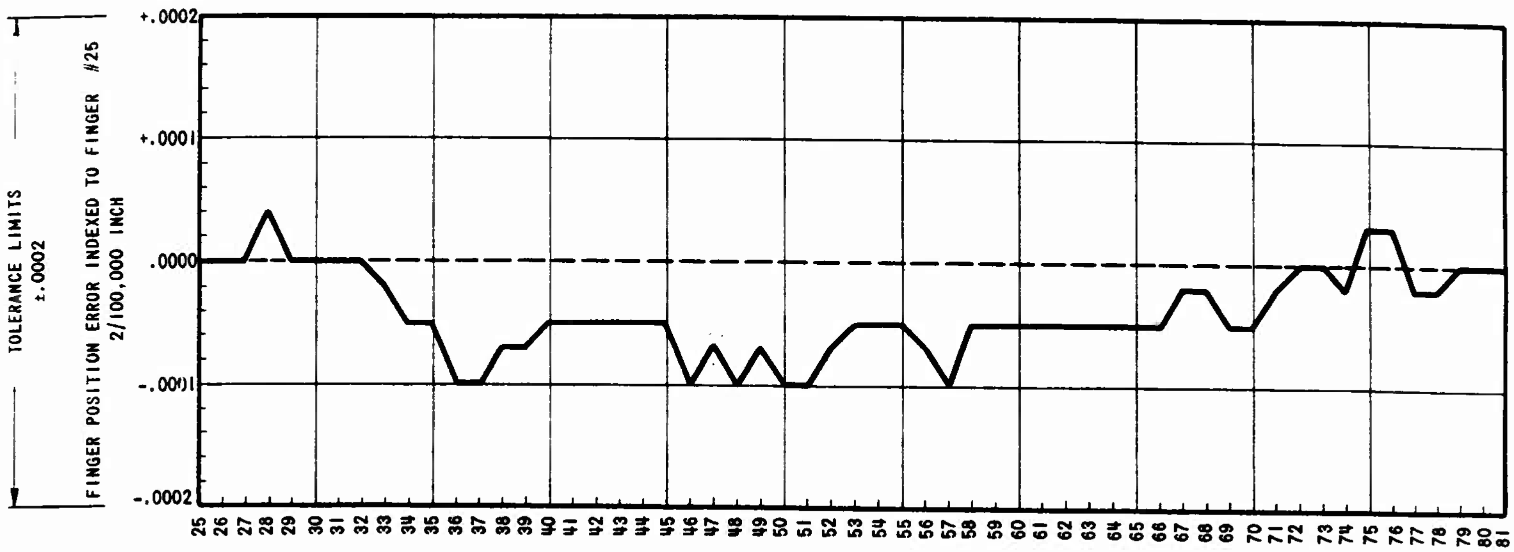


FIGURE 75 BAND 8 CUMULATIVE FINGER SPACING ERROR

Machining methods were refined to take full advantage of the improved hob accuracy. The QKA857 crowns, for example, showed a reduction in completed delay-line error of 200% at the completion of the program. Less dramatic improvements in delay line quality were also observed in the case of QKA855 and QKA851 tubes.

The interdigital crowns that make up the delay lines of these M-type backward-wave oscillators require drilled holes for attachment to the cylinder anodes. During this program, the method utilized was to make use of a common jig that located the drilled holes in the interdigital crowns and the cylinder anode. Thus, even if there was an error in the jig, it would not cause misalignment of the assembly. Location of these holes by a common jig effects a large savings over such other methods as perhaps jig boring.

b. Soles

Another important element of the tube is the sole electrode. Soles for the tubes of the compatible series were constructed of OFHC copper because of its high thermal and electrical conductivity. The high thermal conductivity aids greatly in the thermal frequency tracking ability of this series of tubes. The weight of the early soles, however, posed a problem due to vibration. The inside dimensions of these soles were hobbed to lighten them while still maintaining rigidity.

This technique also considerably reduces the cost of the piece as the inside dimension of the soles does not have to be machined.

c. Other Prime Parts

Other prime parts designed in the course of this program utilize the latest production techniques such as hobbing, coining, stamping, swaging, pressing, etc. An example of some of these parts is depicted in the photographs in the section on common parts.

3. Subassembly Manufacturing Methods

a. QKA851 Delay Line

The Band 2 tube presented a unique problem with respect to the construction of the delay line. At this frequency range, the fingers obtained by the hobbing technique would be too long, which would cause trouble in meeting the vibration requirement of the contract specification. These fingers were constructed of an alloy which is much harder than copper and were made in the shape of a "C". The above features allowed the delay line of the tubes to pass the severe vibrational requirement of the specification.

b. QKA852, QKA855, QA857 Delay Lines

The several crown manufacturing improvements discussed in Section 2a permitted the introduction of further improvements in the technique utilized to assemble crowns into a usable delay line. Earlier delay-line assembly methods, in order to achieve adequate alignment of the mating fingers, involved extensive individual fitting of the crowns to each other and to the cylinder on which they were mounted. The delay-line assembly was accomplished under high power microscopes by skilled technicians who required many months of training and experience to become proficient in this particular operation. The microscope method of alignment was time consuming, required considerable judgement on the part of the technician, and made the training of new personnel most difficult since the instructor and trainee could not observe the in-process work at the same time. Improvements in crown assembly procedures had met with little success because of the limited accuracy of available prime crowns.

The crowns manufactured during this program were assembled into delay lines by means of a new technique which was developed to take advantage of the improved quality and consistency of crown dimensions. This novel assembly method permits the crowns to be aligned in and attached to the cylinder with the aid of a precision optical comparator. The interdigital fingers and the spacing between them are displayed on the face of the comparator at magnifications up to 100 X. A special crown-cylinder holding fixture and modifications to the comparator's optical

system were required. Special comparator charts which outlined the desired finger spacing at the various magnifications were attached to the comparator viewing face to assist the operator.

The optical comparator delay line alignment method was successful in aligning crowns in the QKA857 cylinder assembly with a tolerance of approximately .0003 inch to .0005 inch. This high order of accuracy was achieved with roughly 50% less assembly time than had been required with prior methods. In addition, the optical comparator technique permits the use of lower skilled production personnel. Training time is reduced since the instructor and trainee observe the magnified in-process work simultaneously during the training period.

An additional benefit derived from the optical comparator method was noted at cold test where the VSWR characteristics of the completed delay line are measured. Final adjustment of finger spacing is accomplished at this stage in order to optimize the delay line rf characteristics. A significant reduction in the time required to optimize delay lines fabricated with the improved methods was noted. It is estimated that a 50% reduction in cold test labor costs could be realized when the new method is utilized in production.

c. <u>Sole Mounting Technique</u>

An improved assembly method was developed to facilitate mounting of the gun-sole assembly in the exact position required. The sole must be centered to a high degree of precision within the crown-cylinder assembly. The QKA857 specification, for example, requires that the sole O. D. be concentric with the crown I. D. within .001 inch. Conventional assembly procedures were utilized for a series of heliarc welds to attach the sole to its support element. The heliarc weld method frequently resulted in out-of-specification centering of the sole because of distortions created by the intense heat of welding.

The improved sole mounting technique which was developed to replace the heliarc method employs a series of screws to attach the sole to the sole support structure. The finish and flatness of the mating sole and sole-support surfaces are controlled to insure good thermal contact between the two assemblies. Improved sole centering has been obtained with the new method. For example, the heliarc method of mounting QKA857 soles resulted in out-of-specification sole centering in one out of four assemblies, while the improved method permits fully acceptable sole centering to be achieved in all cases.

The improved sole centering technique has the following advantages.

1. The assembly labor required to center and attach the gun-sole assembly is reduced by about 50%.
2. Tube performance and uniformity are improved because of the greater dimensional accuracy achieved.
3. The danager of tube damage due to heliarc weld splash is eliminated.
4. Procedures for removal and replacement of gun-sole assemblies are simplified.

d. <u>Subassembly Brazing Techniques</u>

The cylinder-anode assembly, sole-support assembly, and exhaust assembly were designed and developed in a manner which permits these assemblies to be brazed in a continuous-belt production furnace. This arrangement minimizes the amount of labor required to accomplish the braze since time-temperature schedules for the fire-heat, braze and cool cycles are automatically controlled by the furnace. Labor is only required to load and unload the assemblies. Automatic time-temperature control also minimizes the loss of assemblies caused by human error.

e. Cylinder - Dummy Anode - Collector Assembly

The dummy anode and collector electrodes must be located accurately on the cylinder inner diameter. These elements must be joined to the cylinder in a manner which will provide efficient thermal conduction between the electrodes and the cylinder heat sink. Earlier M-BWO assembly methods utilized brazing techniques to attach the elements. The brazing method did not provide completely satisfactory electrode location and allowed variations in thermal contact due to solder skips. The technique utilized on this program was to broach these elements as an integral part of the anode coolant jacket assembly. This method is accurate and exactly reproducible from part to part.

This technique also effected a cost saving in inspection, since the exactly reproducible nature of this technique requires sample inspection only.

f. Output Window Assembly

During the course of this program, a unique design of ceramic output window was developed for use with the DR-19 waveguide on the Band 6 and 8 tubes. This vacuum window assembly is constructed in the actual DR-19 output flanges of the tubes and has a VSWR of less than 1.1 over the desired frequency ranges. The small amount of space required by these windows allows for a longer transition from the DR-19 waveguide to the delay line of the M-type backward-wave oscillator. This longer transition results in a lower over-all VSWR and less rf loss in the output system of the tube.

g. "Cold Test" Methods

During the construction of M-type backward-wave oscillators, the cylinder crown anode assembly must be inspected to determine the characteristics of the interdigital delay line. This testing is termed cold testing and it consists of measuring the VSWR of the delay line looking into the output. The dispersion and attenuation of the delay line can also be measured, if required. During the course of this program, the reflectometer set-up allowed the frequency band of the

particular tube to be swept while looking at the VSWR of the tube. This is much faster than the point-by-point method once used. This technique results in a cost saving by reducing the inspection and adjustment time and is ideally suited to production utilization. A go-and-no-go line versus frequency can be scribed on the face of the oscilloscope, making this equipment suitable for less technically skilled personnel.

h. Exhaust Processing

The four tube types of the program were processed with stationary exhaust equipment at Spencer Laboratory. These stationary units were designed to simulate the vacuum equipment employed in the in-line production exhaust facility located at the Waltham plant. The exhaust processing schedules used during the program were compatible with the requirements of the in-line production system.

The above precautions were taken to insure that the tubes developed during the program would be capable of being exhausted at production rates at the in-line exhaust facility.

COST REDUCTION

On 6 February 1962, word was received that Raytheon's request for permission to procure long lead time items for Phase II under Contract No. AF33(600)-43395 had been granted. Although requests were released for only small quantities of parts, the units had been sufficiently value engineered during the development phase of the contract to effect definite savings in material costs.

The following chart illustrates some of the items where this stringent engineering approach during development has paid multi-dividends in the ordering of long lead time items for refinement.

Part No.	Part Name	Cost	
606-773	Sleeve		60% Cost Reduction
606-770	Stanchion		75% Cost Reduction
605-667	Magnet		43% Cost Reduction
609-905	Sleeve		89% Cost Reduction
607-051	Plate Magnet		42% Cost Reduction
606-822	Pole Adapter		59% Cost Reduction
606-817	Pole Cover		67% Cost Reduction
608-999	Pipe O/P		32% Cost Reduction
608-515	Collector		77% Cost Reduction
609-742	Ridge O/P		46% Cost Reduction
606-772	Adapter		64% Cost Reduction
606-815	Cover		57% Cost Reduction
606-802	Pole		50% Cost Reduction
609-742	Ridge O/P		55% Cost Reduction

0 20 40 60 80 100

Percentage of Cost

1. Production Liaison

To design these tubes for production, a close liaison with the appropriate production personnel was maintained during the course of this program. In fact, two of the development engineering personnel are representatives of a committee devoted to reducing the cost of the QKA853, a tube of the compatible series presently in large-scale manufacture. Efforts such as these will reduce the cost of tube, and this can be demonstrated by the present cost of $1, 100 each for the QKA853 in large quantities.

2. Common Parts

During the course of this program, as many parts and assemblies of the various tubes of the compatible series as possible were made identical. This will effectively lower the future cost of these tubes, and the advantages of large quantity purchasing can be enjoyed. Many of the parts and assemblies are also utilized on the QKA853 tube presently in production. This will also aid in lowering the tube costs as the production tooling required for manufacturing of the parts is already available in many cases. A series of photographs showing these common parts and assemblies follows:

Figure 76 - Common Parts Tubes 1 through 8.
Figure 77 - Common Parts and Assemblies Tubes 1 through 5.
Figure 78 - Common Parts and Assemblies of the QKA853 used on Tubes 1 through 5.
Figure 79 - Common Parts and Assemblies Tubes 6 through 8.
Figure 80 - Common Parts and Assemblies of the QKA853 (tube 4) used on Tubes 6 through 8.

3. Manufacturing Cost Reduction

a. Prime parts cost reduction has been achieved through the use of common parts where possible. Examples of common design follows:

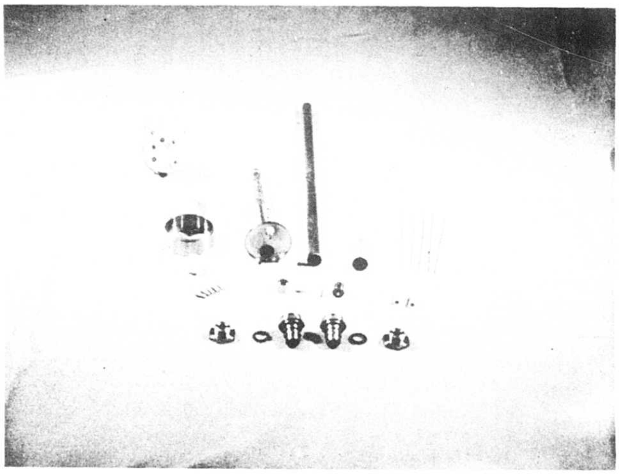


FIGURE 76 COMMON PARTS TUBES 1 THROUGH 8

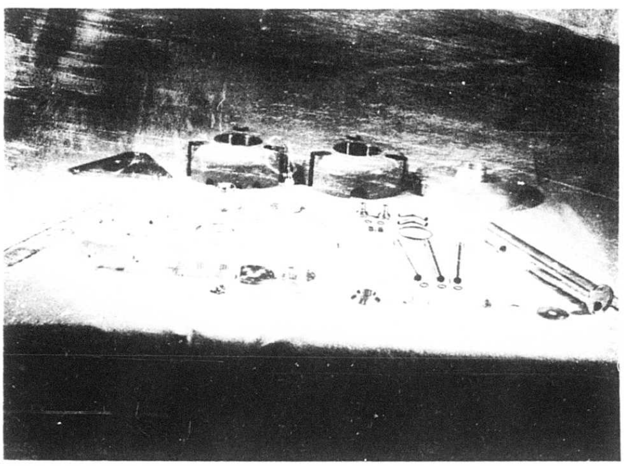


FIGURE 77 COMMON PARTS AND ASSEMBLIES TUBES 1 THROUGH 5

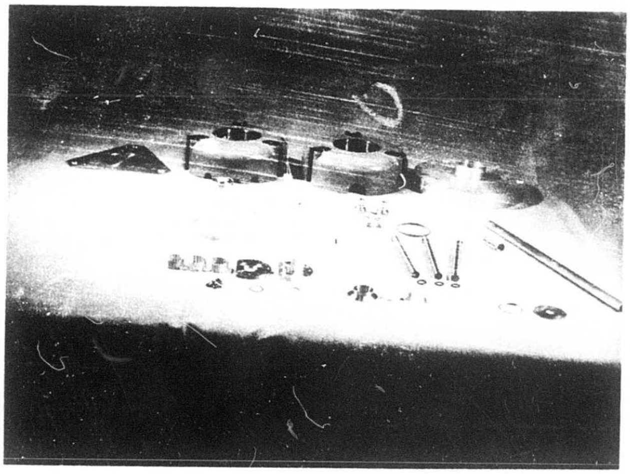


FIGURE 78 COMMON PARTS AND ASSEMBLIES OF THE QKA853 US
ON TUBES 1 THROUGH 5

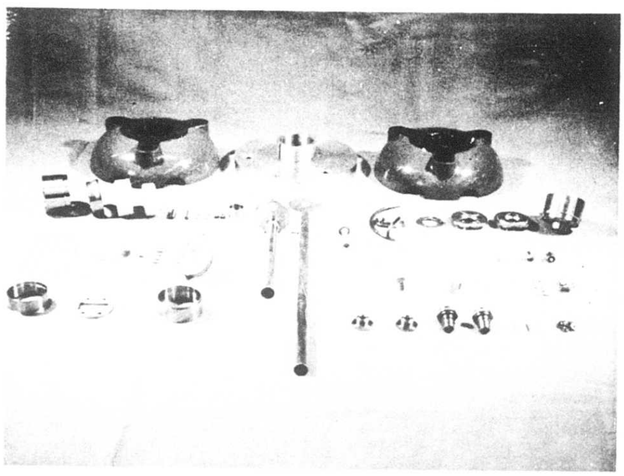


FIGURE 79 COMMON PARTS AND ASSEMBLIES TUBES 6 THRO

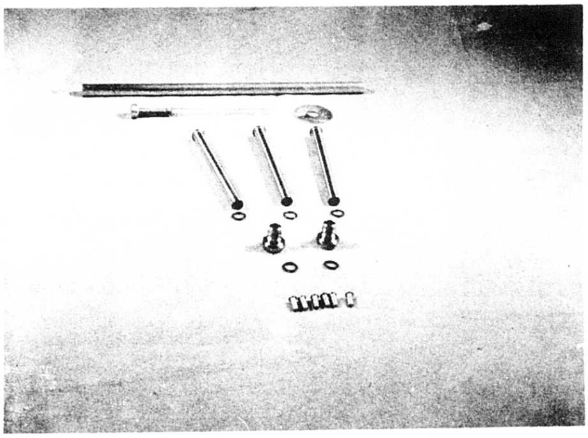


FIGURE 80 COMMON PARTS AND ASSEMBLIES OF THE QKA853 (TUBE 4) USED ON TUBES 6 THROUGH 8

(1) Bands 2 and 3

(a) Anode assembly contains common coolant jacket, baffle and miscellaneous plumbing.

(b) Output assembly contains all common parts with the exception of the outer sleeve, inner sleeve, pipe and coupling.

(c) Sole support and exhaust assemblies contain all common parts with the exception of the poles and covers.

(d) Gun assembly contains common heater cathode and ceramic parts.

(e) Packaging parts are all common.

(2) Bands 6 and 8

(a) Sole support assembly contains all common parts with the exception of the pole and covers.

(b) Exhaust assembly utilizes bands 2 and 3 parts with the exception of the poles and covers.

(c) Gun assembly contains common ceramic assemblies, support legs and gun mounts.

(d) Packaging parts are all common with the exception of pole extensions.

b. Processing costs have been reduced by designing all tubes to be capable of processing on the mass-production in-line exhaust system located in the Waltham plant.

SUMMARY, CONCLUSIONS AND RECOMMENDATIONS

1. Summary and Conclusions

During the Phase I program Band 2, Band 3, Band 6 and Band 8 tubes were redesigned and sufficient shop models of each were constructed to establish a production refined design. Electrical, mechanical and process specifications were brought to within 10% of completion. The final tubes constructed during this phase met all of the electrical requirements.

In the Phase II program, sample lots of Band 2, 3, 6 and 8 tubes were production-fabricated in accordance with the approved final specifications. Environmental and life tests were conducted on several tubes of each type, and an investigation was made into the causes of failure (in some instances). The mechanical, processing and electrical specifications were completed, and three tubes meeting the electrical requirements were put to one side for delivery to the Air Force when notice of acceptance and approval has been received.

From the environmental results obtained on the QKA851, QKA852, QKA855 and QKA857, it can be concluded that these tubes will comply fully with the specified vibration and thermal requirements. Moreover, since tubes of each type have run over four hundred hours each without suffering electrical fatigue and have continued thereafter to perform within the specified limitations, it can be concluded that the tubes comply fully with the life requirements.

Prime part cost reduction has been achieved through the use of common parts wherever possible, and processing costs have been reduced by designing all tubes for processing on the mass production in-line exhaust system. At the present time, the QKA851, QKA852 and QKA857 tubes are ready for transfer to Raytheon Production Facility. The QKA855 has already been transferred to production.

2. Recommendations

With the satisfactory completion of the Phase II requirements, in particular the successful refinement of the Band 2, Band 3, Band 6 and Band 8 tubes, only the Band 5 and Band 7 tubes of the compatible series remain to be produced.

Additional QKA851 tubes should be built using the crown assembly technique for further refinement of the jigs, splines and fabrication method.

It is recommended, therefore, that time and funds to be made available to complete the evaluation and further refinement of the cylinder crown assembly technique with the objective of providing an improved and more reproducible version of the QKA851.

Moreover, the technical background established on this tube can be readily adaptable to other tube types using similar delay lines. However, within the present scope of time, funding and objectives under this contract, the principal effort was concentrated on the existing cylinder assembly technique in order to meet contractual objectives.

Concurrently with the above effort, the Beam Miser principle was satisfactorily established by Raytheon under contract AF33(600)-40992, Hallicrafters P. O. 94762. With the successful incorporation of the Beam Miser unit in the S-band M-type backward-wave oscillator (QKA987) it is recommended that future work be pursued towards achieving a compatible series of tubes with substantially higher power. The Beam Miser in its role as a depressed collector can be employed to increase efficiency and/or rf power as well as to reduce power supply requirements and heat dissipation in the QKA851, QKA852, QKA855, and QKA857 tubes. It has been demonstrated that this can be done with no added systems complications.

The Raytheon Microwave and Power Tube Division has demonstrated its ability to extend the capabilities of microwave power tubes by designing new tube types and by improving the materials components and techniques associated with existing tubes. With broad experience in the development of microwave power tubes and the improvement of their performance, Raytheon Company is well qualified to organize and conduct a program to successfully produce Band 5 and Band 7 tubes.

BIOGRAPHIES

Dr. Howard Scharfman

Dr. Howard Scharfman is Manager of Engineering for the Microwave and Power Tube Division at Spencer Laboratory, Burlington, Massachusetts, and is responsible for the Magnetron Laboratory, Crossed-Field Devices Laboratory, High Power Tube Laboratory, Beam Tube Laboratory, Materials, Processes and Techniques Laboratory and all Engineering Services.

Since joining Raytheon in 1954, he has held many responsible engineering management positions; most recently serving as Manager of the Special Microwave Devices Operation. At Raytheon, he has worked in all phases of ferrite devices and materials, and holds a number of patents in these fields. He has presented many papers on these subjects.

During World War II, he served in the U. S. Army from 1943-46.

He received his B. S. E. E. degree from New York University in 1947, and his M. S. E. E. degree from Northwestern University in 1948. From 1948-50, he taught undergraduate electrical engineering at the Polytechnic Institute of Brooklyn, New York.

In 1950, he joined the Antenna Section of the Boeing Airplane Company, Seattle, Washington, where he was engaged in the research and development of receivers, antenna pattern ranges, and aircraft antennas.

From 1951-54, he was employed at the Johns Hopkins University Radiation Laboratory where he worked on UHF and VHF circuits and microwave scattering problems while completing his doctoral studies. He received his D. S. E. E. degree from Johns Hopkins University, Baltimore, Maryland, in 1954.

Dr. Scharfman is Chairman of the Raytheon Microwave Components Patent Committee; Chairman, Waveguide and Components Subsection of the RF Transmission Components Section of the Electronic Industries Association; and a senior member of the IEEE. He is a past member of the Microwave Amplifier Committee and was Assistant Chairman of the 1959 National Convention of the PGMTT of the IEEE.

He was born in New York City in 1924.

Edward C. Dench

Mr. Edward C. Dench is Manager of the Crossed-Field Devices Laboratory of the Raytheon Mic rowave and Power Tube Division and has been assigned the additional responsibility for coordinating certain special microwave tube programs. Since joining the Company in 1947, he has worked on magnetrons and microwave amplifier projects, and has been actively associated with the Raytheon development of the crossed-field high power backward wave oscillator, the crossed-field amplifier, and the "Bitermitron" power booster. His laboratory has also been engaged in research and development, product refinement, and manufacturing methods projects relating to such devices.

Originally from New Jersey, where he was born in 1916, Mr. Dench attended Worcester Polytechnic Institute on a Westinghouse Memorial Scholarship, and was awarded a B.S. in E.E. degree with High Distinction in 1939. He went to M.I.T. on a Tau Beta Pi Fellowship and received a M.S. in E.E. degree in 1940. His thesis subject: "Investigation of a Resonant Cavity Magnetron", was one of the earliest researches on the resonant cavity type magnetron in America.

While an undergraduate, Mr. Dench worked for the Westinghouse Lamp Division, Bloomfield, New Jersey, and since graduation he has worked for: The Research Laboratories, Interchemical Corporation, New York City, as a senior physicist in the development of electrical instruments, computers, and facsimile; for Allen D. Cardwell, Inc. Plainville, Connecticut, as an electronics engineer in the development of test equipment, and as a project engineer on a radio direction finder; for the A. T. Hatton Company, Hartford, Connecticut, as an industrial electronics control engineer; for the Crystal Research Laboratories, Hartford, as an engineer in the field of piezo-electric devices. Concurrently with his employment during World War II, he instructed several courses in electronics as a member of the staff of the University of Connecticut.

He has made notable contributions in the fields of gas discharges, fluorescent lighting, computers, electronic color correction, ultrasonics, high pressure mercury arc lamps and microwave tubes; and holds a number of patents (approximately 50) for improvements in these fields.

Mr. Dench is a member of Sigma Xi, Tau Beta Pi, and IEEE (Senior). He is a registered Professional Engineer in Connecticut and Massachusetts.

Peter Janis

Peter Janis is a Section Head in the Crossed-Field Devices Laboratory of the Raytheon Microwave and Power Tube Division. Since joining the company in 1957, he has been responsible for the design, development and production refinement of several crossed-field backward-wave oscillators.

Originally from New York, where he was born in 1911, Mr. Janis attended Cooper Union School of Engineering on a competitive scholarship and was awarded a B. S. E. E. degree in 1941. He completed the I. E. course at New York University in 1942 and other specialized seminar courses in physics, glass technology, metallurgy, circuits, conventional and traveling-wave vacuum tube design. For several years he taught theory and design of electronic circuits, A. M., F. M., T. V., and color receivers at RCA Institute.

While an undergraduate, Mr. Janis worked in Power Engineering for the New York Transit System. Following graduation, he became a Senior Engineer for RCA Victor, Inc. and received a War Production Merit Award for engineering contributions. His work at RCA Victor included development of several special purpose tubes and glass engineering.

Mr. Janis then became Section Head of Microwave Tubes for Sylvania Electric Products, Inc. where he was responsible for design, development and pilot line production of traveling-wave amplifiers, backward-wave oscillators, reflex klystrons, planars, and other special purpose tubes, including tube components for use in RF heads tuning 2 and 3 octaves, and tube components for millimeter wavelengths. He presented several classified papers on this work and published "Wide Range Local Oscillator" in the April, 1952 edition of Tele-Tech.

Prior to joining Raytheon, Mr. Janis was Chief Engineer at Amperex Electronics Corp. While there, he contributed to the design, development and production refinement of: long life, wide pulse and high pulse current magnetrons; low noise CW power klystrons; low voltage magnetrons, and hydrogen thyratrons.

Mr. Janis is a member of the IEEE(Senior), and was a member of several JETEC committees and of Adelphi College Research Center Planning Committee. He is a registered professional engineer in Massachusetts. He has several patents and disclosures on klystron discharge devices and crossed-field tubes.

Thomas H. Lavin

Mr. Thomas H. Lavin is Section Head, Services, in the Crossed-Field Devices Laboratory of Spencer Laboratory. Since joining the Company in 1957, he has been involved in the design, development and production refinement of several crossed-field backward wave oscillators. He has held his present position since 1960.

Mr. Lavin's section includes the personnel, equipment, and facilities necessary to construct, process, and test the various tubes and components developed by the Crossed Field Devices Laboratory. In addition, this section provides material control, design and administrative support to the engineering sections. Mr. Lavin is responsible for the development of new manufacturing, processing, and testing facilities and techniques for the Crossed Field Devices Laboratory. He was recently the project engineer on a Company funded program which has demonstrated the feasibility of ceramic-mounted photocopied delay lines for crossed-field microwave devices.

He attended Rensselaer Polytechnic Institute, Troy, New York, from 1946-51, and received the degrees of Bachelor of Management Engineering in 1950 and Bachelor of Mechanical Engineering in 1951.

Mr. Lavin served in the United States Air Force from 1951-57 as a meteorologist. He attained the rank of Captain. Concurrently, he attended Pennsylvania State University and received a Bachelor of Science degree in meteorology in 1954.

He was born in Troy, New York, in 1928.

R. T. Mannette

Russell T. Mannette is a Section Head in the Crossed-Field Devices Laboratory of the Raytheon Microwave and Power Tube Division. Since transferring to the laboratory in 1952, he has been involved in the development and refinement of a number of high power crossed-field amplifiers and backward-wave oscillators, extending from P-band to X-band, and including miniaturized BWO's.

His responsibilities have extended from initial engineering phases to final production run. He is responsible for coordination and liaison in both areas, and has considerable experience with the organization of production line techniques.

Originally from Providence, Rhode Island where he was born in 1925, Mr. Mannette joined the United States Marine Corps in 1943 following graduation from high school in Newton, Massachusetts. While in the Marine Corps he attended the Naval Aviation Ordnance School at Memphis, Tennessee.

Following his discharge, Mr. Mannette majored in basic engineering at Newton Junior College and after graduation in 1948, began work at Raytheon Company. During the subsequent years, Mr. Mannette studied at Northeastern University's Lincoln Technical Institute, receiving an Associate Degree in Mechanical Engineering in 1952 and an Associate Degree, with honors, in Electrical Engineering in 1955.

Mr. Mannette is a Member of the IEEE and a Registered Professional Engineer in Massachusetts.

Richard B. Deming

Mr. Richard B. Deming is an engineer in the Crossed-Field Devices Laboratory of Spencer Laboratory, the Raytheon Microwave and Power Tube Division's main research and development facility.

He joined the company in 1957 and worked on the development of backward-wave oscillators and Bitermitrons until he entered the service.

From 1958-61, Mr. Deming served as a First Lieutenant in the U. S. Army Ordnance Corps as a section head in the missile system engineering evaluation program at the White Sands Missile Range, New Mexico. He also attended the Army Ordnance Guided Missile School at Redstone Arsenal, Huntsville, Alabama, in 1958-59.

Returning to Raytheon in 1961, he was the project engineer in the initial design and refinement of an X-band backward-wave oscillator and is currently working on the development of a miniaturized S-band backward wave oscillator.

Mr. Deming received his A. B. degree in physics from Middlebury College, Middlebury, Vermont, in 1957. He has completed courses in mathematics at the University of New Mexico in 1960, and is now working for his M. S. degree in physics from Northeastern University, Boston, Massachusetts.

He was born in Boston, Massachusetts, in 1935.

James M. Gallagher

Mr. James M. Gallagher is an Engineer in the Crossed-Field Devices Laboratory of Spencer Laboratory, the Raytheon Microwave and Power Tube Division's main research and development facility. Since joining the Company in 1960, he has been engaged in the development of M-type backward-wave oscillators.

Mr. Gallagher attended Boston College on a competitive scholarship and was awarded a B. S. degree in Physics in 1954. During his senior year Mr. Gallagher was a research assistant in the Boston College Ultrasonics Laboratory. While as an undergraduate he was also employed as a physicist for the Cambridge Air Force Research Center. He attended the Boston College Graduate School on a research assistantship in 1954 where he continued his Studies in Physics. In 1955, Mr. Gallagher studied Physics at the Boston University Graduate School and was a research assistant in the Boston University Physical Research Laboratory. While a graduate student he was also employed as a physicist for Lincoln Laboratories in Lincoln, Mass.

Mr. Gallagner then became an engineer for Sylvania Electric Products Inc. in the Advanced Development Section at Woburn, Mass., where he was responsible for the development of M-type backward-wave oscillators. Later he worked as an engineer for the Sperry Gyroscope Co., Great Neck, N. Y. in the product refinement of high power pulsed traveling wave tubes.

Prior to joining Raytheon, Mr. Gallagher was an engineer for Bomac Laboratories in Beverly, Mass. While there, he was responsible for the design and development of beacon magnetrons and M-type backward-wave oscillators.

He was born in Lawrence, Mass. in 1933.

John S. George

Mr. John S. George is a tube development engineer in the Crossed-Field Devices Laboratory of Spencer Laboratory, the Raytheon Microwave and Power Tube Division's main research and development facility. He joined the company in 1955 and has been engaged in the development and refinement of P-band backward wave oscillators. He is currently engaged in the development and refinement of a C-band BWO.

From 1955-60 while a student at Boston University, he worked as a precision inspector in the Quality Control Section of the Division. Mr. George received his B. A. degree in physics from that school in 1960.

From 1951-55, he served in the U. S. Air Force Far East Command as a control tower operator and a ground controlled approach operator and technician. He held the rank of Staff Sergeant.

Mr. George was born in Lowell, Massachusetts, in 1932.

Richard G. McCarthy

Mr. Richard G. McCarthy is an engineer in the Crossed-Field Tube Laboratory of Spencer Laboratory, the Raytheon Microwave and Power Tube Division's main research and development facility. Since joining the company in 1956, he has been engaged in the research, design and development of crossed-field tubes. In addition since 1960 Mr. McCarthy has been the liaison engineer in the transfer of several M-BWO's to the Raytheon production facilities. His duties included initial engineering responsibility in production and he has continued to serve as a technical consultant with production engineers.

Mr. McCarthy received his A. B. in physics in 1955 from Boston College, Newton, Massachusetts. He spent the summer of 1955 as a research engineer at the Bendix Aviation Corporation, Sidney, New York.

From February, 1955 to June, 1956, while a student at Boston College Graduate School, he was employed as a teaching assistant there. Mr. McCarthy is presently pursuing graduate studies at Northeastern University, Boston, Massachusetts, for his M. S. in physics.

He was born in Quincy, Massachusetts, in 1932.

Kenneth F. Morman

Mr. Kenneth F. Morman is a research engineer in the Crossed-Field Devices Laboratory of Spencer Laboratory, the Raytheon Microwave and Power Tube Division's main research and development facility.

He joined the company in June, 1960, and has been engaged in the study of crossed-field amplifiers.

Mr. Morman was a co-operative student at the General Motors Institute, Flint, Michigan from 1954-58. Where he received a diploma in mechanical engineering.

He received his B. S. E. degree in electrical engineering from the University of Michigan in 1959, and his M. S. degree in electrical engineering from the University of Illinois in 1960. He is currently on leave of absence at the University of Michigan where he is working toward his Doctorate degree in Electrical Engineering.

Mr. Morman is a member of Eta Kappa Nu, Pi Mu Epsilon, and the IRE. He was born in Chicago in 1937.

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